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- 22a. NAME OF RESPONSIBLE INDIVIDUAL: ERNEST A. HAYGOOD, 1st Lt, USAF
- 22b. TELEPHONE (Include Area Code): (513) 255-2259
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THROUGH OPERANT TRAINING:
THE EVALUATION OF PSYCHOLOGICAL AND PHYSIOLOGICAL
MECHANISMS FACILITATING ACUITY ENHANCEMENT

BY

LERAY LYLE LEBER, B.S., M.A.

A Dissertation submitted to the Graduate School

in partial fulfillment of the requirements

for the Degree

Doctor of Philosophy

Major Subject: Psychology (Engineering)

Related Area: Experimental Statistics

New Mexico State University

Las Cruces, New Mexico

December 1988

"Improving Visual Acuity of Myopes through Operant Training: The Evaluation of Psychological and Physiological Mechanisms Facilitating Acuity Enhancement," a dissertation prepared by Leray Lyle Leber in partial fulfillment of the requirements for the degree, Doctor of Philosophy, has been approved and accepted by the following:

William H. Matchett
Dean of the Graduate School

Chairman of the Examining Committee

9 December 1988
Date

Committee in charge:

Dr. Dennis B. Beringer, Chairman

Dr. Victor S. Johnston

Dr. David W. Martin

Dr. Kenneth R. Paap

Dr. G. Morris Southward

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VITA

[redacted]

1976 - B. S., United States Air Force Academy, Colorado

1976-1977 - U.S. Air Force, Undergraduate Helicopter Training, Fort Rucker, Alabama

1977-1981 - Chief of Aircrew Standardization and Evaluation, Detachment 6, 37th Aerospace Rescue and Recovery Squadron, McConnell Air Force Base, Wichita, Kansas

1979 - M.A., Webster College (On Base Extension, McConnell A.F.B.)

1981-1983 - Director of Current Operations, 37th Aerospace Rescue and Recovery Squadron, F.E. Warren Air Force Base, Cheyenne, Wyoming

1983-1985 - M.A., New Mexico State University, Las Cruces, New Mexico

1985-1987 - Instructor, U.S. Air Force Academy, Colorado Springs, Colorado

1987-1988 - Ph.D. (all but dissertation defense), New Mexico State University , Las Cruces, New Mexico

1988 - Assistant Professor, U.S. Air Force Academy, Colorado Springs, Colorado

PROFESSIONAL AND HONORARY SOCIETIES

Human Factors Society

Association of Aviation Psychologists

Aerospace Medical Association

PUBLICATIONS

Leber, L. L., Roscoe, S. N., & Southward, G. M. (1986). Mild Hypoxia and Visual Performance with Night Vision Goggles. Aviation, Space, and Environmental Medicine, 57, 318-324.

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IMPROVING VISUAL ACUITY OF MYOPES
THROUGH OPERANT TRAINING:
THE EVALUATION OF PSYCHOLOGICAL AND PHYSIOLOGICAL
MECHANISMS FACILITATING ACUITY ENHANCEMENT

Doctor of Philosophy in Psychology
New Mexico State University
Las Cruces, New Mexico, 1988
Dr. Dennis B. Beringer, Chairman

Many studies have substantiated that unaided visual acuity is an alterable process. If acuity can be enhanced, it could benefit some of the nearly one billion individuals who have myopia or "nearsightedness". This study investigated the degree to which repeated attempts to resolve stimuli made progressively smaller facilitated posttraining acuity.

Thirty-six subjects were divided into six groups with balanced pretraining acuities ranging from 20/25 to 20/100. A different combination of retreating or "fading" Tumbling E stimuli and performance feedback was presented to each group. Pre- and posttraining assessments were made of Snellen letter acuities, Ortho-Rater checkerboard acuities, high- and low-contrast Tumbling E resolution distances, blur tolerances, and contrast sensitivities.

On the average, after five consecutive-day, one-hour participation sessions, subjects trained with performance-contingent fading and feedback displayed the most improvement with stimuli used in training as well as with all but one of the tests incorporating stimuli not used in training. There were significant performance facilitation differences between groups, when fading and feedback day-1 and day-5 performances were compared or when fading and feedback posttraining performances were contrasted with performances of untreated subjects.

Feedback appeared to be a critical component in subject motivation. Contrast sensitivity assessment appeared promising as a screening device to select those who might benefit most from training. Changes in acuities were predictable from the linear combination of changes in defocused letter and Tumbling E recognition scores and initial Snellen letter acuities. Endurance of acuity enhancement was confirmed after subjects maintained their performance levels 4-6 weeks after training.

Twenty-six subjects were divided among treatment and control groups to investigate the degree to which some of the factors that influence acuity could be trained. Pupillary control training resulted in significant volitional control of pupil size. Neither five days of accommodative range training nor blur interpretation training resulted in significant changes in these facets of

acuity. Contrast sensitivity was differentially influenced by acuity training; those receiving either accommodative range or blur training displayed significant contrast sensitivity enhancement. It may be the recognition component of these regimens that facilitates grating resolution.

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INTRODUCTION

There is much evidence to suggest that unaided visual acuity is not an unalterable physiological process. Psychological processes allow some degree of pupil control, blur interpretation, accommodative flexibility, and other cognitive mediation of acuity. This research will examine some of the underlying dynamics of acuity. Its aim is to analyze the trainability of acuity, substantiate some of the psychological mechanisms of acuity, and quantify their relative contributions to acuity enhancement. Such research is necessary to assure accurate acuity assessment of pilot training candidates, commercial pilots, operators of automobiles, baseball umpires, and anyone else who must have vision commensurate with some acuity criterion.

Visual acuity is a primary determinant of whether a potential aviator is allowed to enter pilot training or maintain pilot qualification. A primary source of United States Air Force pilot candidates is the Air Force Academy and, accordingly, one of its goals is to both recruit potential pilots and have graduates enter pilot training. This requires that Academy cadets have good eyesight upon entrance and that they maintain their acuity during their four-year enrollment. Eighty-five percent of the 945-member Class of 1989 entered with pilot qualifying 20/20 visual acuity, however, only 59 percent demonstrated that acuity in their commissioning physicals (J. M. Koreman, personal communication, March 7, 1988). If the assessment of these candidates' acuity is not accurate, some may be unfairly eliminated.

Many candidates will likely receive waivers allowing them to enter pilot training without optimum, 20/20, unaided acuity, yet the variability of spatial acuity as assessed with current procedures leaves suspect whether a

one-time sample of an untrained person is an adequate test. An optometrist at the Academy stated that although measured refractive error remains relatively stable over testing sessions, acuity assessed by a subject's recognition threshold for small-black letters varies by as many as three lines on the Snellen chart (J. A. Ricks, personal communication, March 4, 1988). This finding along with many instances of acuity modification addressed in this introduction suggests that acuity may be changeable.

There is growing interest by both psychologists and optometrists in the potential contributions psychology may make to the understanding and treatment of visual disorders. Myopia researchers have addressed topics in the field of psychology including perception, psychometric testing, behavioral genetics, personality types, physiological processes, hypnosis, and learning (Woods, 1946; Sloan, 1951; Blackwell, 1952; Campbell & Westheimer, 1959; Copeland, 1967; Young, 1967; Hirsch, 1968; Lanyon & Giddings, 1974; Provine & Enoch, 1975; Lupica, 1976; Collins, Epstein, & Gil, 1982; Gawron, 1983). The applicability of these investigative findings to myopia depends on whether the emphasis is on the causes and development of the disorder or on its treatment and modification. This introduction will begin with a definition of myopia, then explain how it is assessed, and finally address some of the scientific evidence and yet unanswered questions regarding its etiology and possible treatment.

Nearsightedness

Light rays entering the eye are bent or refracted by the cornea, the aqueous humor, the anterior and posterior surfaces of the lens, and the vitreous humor. In an optically normal or emmetropic eye without refractive

error, distant parallel light rays are refracted such that they converge at a focal point directly on the retina. A myopic eye has excessive refraction and its overaccommodation results in the focusing of parallel light rays in front of the retina.

Myopia, commonly referred to as "nearsightedness", is a visual disorder in which a person can sufficiently change the curvature and thickness of the crystalline lens, or accommodate, to see things that are proximally near but poor focusing flexibility prevents the discrimination of detail at far distances. High degrees of myopia are often accompanied by damage to the eye's fundus and, when extreme, cannot be fully compensated by corrective lenses (Dunphy, 1970), and may result in blindness (Curtin & Karlin, 1971).

In the majority of cases, myopes function normally with some degree of blurred distant vision or they wear corrective contact lenses or spectacles that diverge parallel light rays to compensate for their eyes' excessive optical refraction. The degree of refraction or accommodation required for clear distant vision is measured in diopters (D), the reciprocal of the corrective lens' focal length in meters. A 3.0 D myope cannot focus beyond a distance 1/3 m or 33 cm in front of the eye, a distance called the far point. A myope without correction cannot attain a conjugate retinal image of targets beyond the far point.

Visual Acuity Assessment

A common test of visual acuity and myopia is to have an examinee attempt to recognize individual letters on a chart at a standard distance. The target letters have gone through a number of standardizations (Sloan, 1951), the Snellen Chart being the most commonly used standard assessment tool. Invented in 1862, the Snellen Chart contains rows of

high-contrast solid-black alphabet letters printed on a white background. The letters vary in size and thus when viewed from a fixed distance subtend different visual angles. Viewing devices are frequently used to present acuity targets at a corresponding optical distance; e.g., a Bausch and Lomb Ortho-Rater Stereoscope. To assess distant acuity, the Snellen Chart is typically presented at 20 feet (6.1 m). The examinee's resolving abilities have been confirmed once they discern a predetermined percentage of letters of one size on the Snellen Chart.

Acuity is often expressed as a ratio of a standard distance (20 feet) to the distance of lines of characters that subtend 1 minute of visual arc. Normal acuity, expressed as such a Snellen fraction, is 20/20. An acuity of 20/40 means that for the examinee to recognize a line of characters at 20 feet (6.1 m) the stroke width of the letters must subtend 2 minutes of visual arc such that an emmetrope with no visual anomalies could identify them at 40 feet (12.2 m). An acuity of 20/10 is the lower human limit, and a person with 20/400 acuity is defined as legally blind (Haber & Hershenson, 1980).

The Tumbling E acuity target is a black E on a white background presented in various orientations: gaps rightward, leftward, upward, and downward. The widths of the three projecting limbs and their gaps vary with the size of the overall target, each equal to one-fifth the height and width of the E (see Figure 1). Acuity threshold is taken to be the smallest gap orientation that can be correctly identified a predetermined percentage of the time. When the reciprocal of threshold in minutes of arc is expressed in terms of a decimal, it is called decimal acuity. With gap-type Tumbling E targets, emmetropes can discern breaks subtending less than .5 minute of visual arc (Shlaer, 1937).

The major disadvantage of Snellen and Tumbling E acuity measures is that they provide information about only a limited portion of our perceptual capabilities. They measure the resolving threshold of the visual system to targets with fine detail at high contrasts (stimuli with large relative luminance differences between their black-solid character and their white background). Campbell and Robson (1968) found twice as much contrast was required to detect 1 cycle per degree gratings when the average luminance of the display was low as opposed to high. Owsley, Sekuler, and Siemsen (1983) found the ability to perceive high-contrast grating targets was not related to the ability to perceive low-contrast frequencies as might be encountered at night or under other low-visibility conditions such as fog or reduced illuminance. Similarly, O'Neal and Miller (in press) found subjects' aircraft detection task performances correlated more with their low-contrast letter acuities than standard high-contrast acuities.

Perception of high-contrast letters or symbols is to some degree adequately assessed by these instruments. When myopic disorders are detected, corrective lenses are usually prescribed to improve resolution. The ease with which these high-contrast acuity tests can be administered and their general population acceptance as an understandable and adequate vision metric has led to their widespread use as a model procedure for myopia assessment. Their primary disadvantage is the

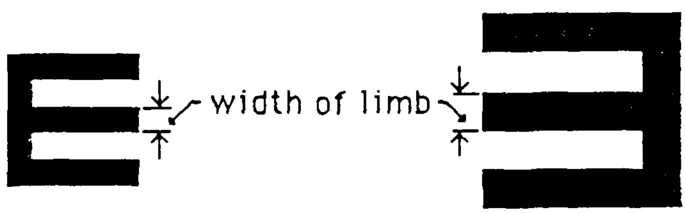

Figure 1. Tumbling E limb width as a function of overall target size.

questionable generalizability of their results to everyday pattern perception encompassing varying degrees of contrast. There is an ever-increasing understanding of what constitutes an adequate stimulus for accommodation (Campbell & Westheimer, 1959; Toates, 1972; Kruger & Pola, 1986). It is possible that targets of varying contrast and extent might improve our detection of visual disorders and our ability to assess the degree of improvement facilitated by lenses, vision exercises, and surgery.

The contrast sensitivity function has been introduced in an attempt to address these inadequacies. Contrast sensitivity is often measured using sinusoidal grating patterns as targets: alternating black and white stripes that vary from dark to light at right angles to their length. The function is derived by measuring the minimum contrasts that allow a subject to resolve gratings against a uniform field over a range of spatial frequencies. The number of light-dark cycles of the grating that subtend 1 degree of visual angle is the spatial frequency of the grating expressed in cycles per degree (cpd). It is this range of contrast sensitivities from approximately 60 cpd to 0.1 cpd that Gervais, Harvey and Roberts (1984) found best predicted recognition of briefly presented letters. Likewise, Ginsburg, Easterly, and Evans (1983) reported that pilots' contrast sensitivities better predicted their target detection performances than did their Snellen letter recognition acuities.

Patterned Occurrence of Myopia

Myopia detected with Snellen and Tumbling E chart recognition techniques is estimated to affect between one-half billion and one billion individuals and is the most prevalent visual disorder in industrialized

countries (Kelley, 1962). Approximately 40 percent of the adults in the United States are myopic to some degree, and nearsightedness is the most common visual problem among children (Michaels, 1975). In recent years there has been an increase in the incidence of myopia (Sperduto, Seigel, Roberts, & Rowland, 1983) with 55 million American myopes. Hirsch (1968) reported that there had been nearly 10,000 articles published concerning the etiology of myopia, and interest in the visual malady has continued to grow with the introduction of extended-wear contact lenses, acuity training, and radial keratotomy.

Myopia appears quite patterned in its occurrence. Angle and Wissmann's (1980) U.S. Public Health Service records review revealed a pattern consistent with that of other literature on myopia (Kantor, 1932; Slataper, 1950; Hirsch, 1952; Dunphy, Stoll & King, 1968; Goldschmidt, 1968):

- Girls are more often myopic than boys.
- Older adolescents are more often myopic than younger adolescents.
- Children from wealthier families are more likely to be myopic than children from poorer families.
- Black adolescents are less likely to be myopic than white adolescents.
- Adolescents in the economically less developed South are less often myopic than adolescents from other parts of the United States.

- Students in higher grades are more often myopic than their peers who have not gotten as far in school.
- People who report spending more time reading in a typical day are more often myopic, as are those with high scores on a test of reading ability.

Studies have also shown myopic individuals to be superior in areas related to intellectual achievement (Hirsch, 1959). However, when Young (1963) replicated some aspects of Hirsch's study but balanced groups for reading achievement, there was no significant correlation between refractive error and intelligence. Likewise, there was no significant correlation between intelligence and refractive error in a subsequent study of Eskimo children in grades 3-6 (Young et al., 1970).

A variety of research has shown small but consistent relationships between refractive error and personality variables (Giddings & Lanyon, 1974). In general, myopes have been reported to be more introverted, anxious, and achievement-oriented than nonmyopes, and to show less motor activity. Harrison (1929) characterized myopes as being more shy, socially awkward, and as having relatively few friends. Rice (cited by Young, 1967) gave a description of the kind of behavior one might expect of myopic children, emphasizing interest in near work rather than outdoor activities, and he characterized the uncorrected adult myope as a "classical introvert" (p. 194). Mull (1948) found that myopic college students scored higher than emmetropes on introversion, as measured by the Bernreuter Personality Inventory. Shultz (1960), however, found no differences between myopes and nonmyopes on the Minnesota Multiphasic Personality Inventory.

It is important to note that all these findings regarding myopes were made from correlational studies, and that evidence for cause-and-effect relationships cannot be drawn. Even with this restriction, however, it is difficult to dismiss the fact that certain personality characteristics appear to be related to myopia, such as introversion and need for achievement. Although there is no direct evidence regarding whether myopia precedes or follows the development of these personality and achievement characteristics, Kelley (1962) feels that myopia is a response to psychological difficulties. To account for Kelley's findings, Palmer (1966) proposed the "gating" hypothesis, whereby "Unrestricted visual input leads to painfully high levels of excitement, and...individuals develop a myopic norm of vision or other visual impediment as a means of 'gating', controlling or reducing stimulus input, so as to avoid being overwhelmed with large quantities of 'unmastered' excitation" (p. 370).

Hereditary and Environmental Influences on Myopia

There has been an interest in the etiology of myopia for centuries with the nativist-empiricist argument keeping up the debate. The nativists assert the biological theory that natural variation between individuals in the growth of the eye tissues, as influenced by their genetic makeup, produces variation in spherical refraction and an occasional myopic condition. Waardenburg (1930) and Otsuka (1956) (both cited by Goldschmidt, 1968) found a higher correlation between the spherical refraction errors of identical twins than between those of fraternal twins. Sorsby (1951) evaluated the concordance of the elements that determine refractive error for monozygotic and dizygotic twins and for control pairs, and concluded that refractive error and the

individual components of the eye are in part genetically determined. Hirsch and Ditmar (1969) reported that the percentage of myopic offspring whose parents were also myopic increased as the degree of offspring myopia increased.

Conversely, when Young (1958) attempted to appraise the hereditary components of myopic refractive errors in same-sex siblings, he found an extremely low correlation of only 0.15. He later found a similar weak correlational role of heredity in myopic monkeys (Young, 1966). Likewise, the extremely variable age of myopia onset suggests that the development of myopia is not hereditarily determined since for a given population and environment other hereditarily determined characteristics in humans tend to have a relatively fixed age of onset (Young, 1977).

James Ware observed a considerable amount of nearsightedness among the officers of the Queen's Guard in England as early as 1813, but virtually none among the nonofficers. Most of the officers were literate, while practically all of the nonofficers were illiterate, causing Ware to conclude that something about the process of reading might be related to the development of nearsightedness (Young, 1977). His conclusion was a forerunner of the empirical argument postulating that environmental factors, particularly those related to near work, play a significant role in the etiology of myopia. Even such a "clear" link between environment and performance is not free of genetic influence. To what degree myopia was common among the officer's families was not addressed by Ware nor Young.

Proponents of the popular empirical "use-abuse" theory view myopia as the result of habitual use of the eye at a near focal length, doing near work. In support of the theory, Holm (cited by Young, 1977) reported that myopia is extremely rare and almost nonexistent in illiterate populations, but is

increasingly common in literate populations. Sato (1964) hypothesized that continued near accommodation leads to the development of an "acquired" aspect of myopia. Correlational studies have likewise found that educated people, who are usually exposed to greater near work such as reading, have greater frequencies and degrees of myopia than do less educated people (Dunphy et al., 1968; Goldschmidt, 1968). Reviewing a U.S. Public Health Service Examination Survey, Angle and Wissmann (1980) found that some of the variance of myopia and much of its socially patterned variance can be explained with the use-abuse theory.

No amount of research may allow differentiation between the genetic and environmental influences on myopia; both are necessary to have observable human performance. Young makes an empirical argument (1958, 1965a, 1966) postulating a hereditary-environmental interactive cause of myopia, with the hereditary components being the less significant. Whether it is purely or primarily a nature or nurture component that influences the onset or progression of myopia may not be answerable, but their interactive component has not only been substantiated but appears more germane to the discussion of myopia's etiology.

Component Analysis of Myopia

In an attempt to detect the effect of different variables on the development of myopia, investigators would like to control some variables while manipulating others and measure resultant refractive changes. Such tests would allow cause-and-effect relationships to be substantiated. The human populace, however, is not readily subjected to the necessary controls for these kinds of studies and ethical considerations obviously discourage

purposeful introduction of a visual disorder upon human beings. Consequently, Young initially performed his tests with primates and conducted experimental manipulations to assess the development of myopia.

When Young (1961) placed adult monkeys in a restricted vision hood which resembled a near-work situation, noticeable myopic shifts were soon evident. At the end of a year, there were 0.66 to 1.0 D changes toward myopia and he found that the longer the primates' vision was restricted to near work, the greater the amount of myopia they developed. In a subsequent study, Young found that greater amounts of myopia developed in monkeys kept in a laboratory for an extended period than in monkeys kept in an open, outdoor environment (Young, 1966).

In 1969, Young et al. conducted a field study of Eskimos in Barrow, Alaska. The circumstances presented a rare opportunity to assess the roles that both heredity and the environment play on the development of myopia. Prior to federally mandated schooling for Eskimo children, few of the children, their parents, or their grandparents were literate. Thus, nearly 10 years after required schooling, Young conducted a test to detect the effect of reading as well as heredity on the development of myopia. The investigation revealed the grandparents had no myopia, the parents had very little, but that 58 percent of their offspring were myopic. There was also a significant correlation between sibling status and myopia development. Although these findings fail to rule out a genetic tendency toward myopia, Young postulated they are the result of similar factors operating on the siblings, such as parental attitudes toward reading and school work. This suggests that heredity might not be a primary determinant of myopia and,

since the major difference between the older and younger Eskimos was reading and other near work, that this was the likely cause for the development of myopia in children.

According to the use-abuse theory, there is something about near work, likely the process of accommodation, that appears to be intimately involved with the development and progression of myopia. Young (1981) found axial length was the major physiological correlate with primate near-work-induced myopia. When he prevented monkeys from accommodating near through drug-induced paralysis of the muscles that control accommodation (cycloplegia), myopia development was inhibited (Young, 1965b). Bedrossian (1964) likewise significantly slowed the development of myopia in children through administration of a cycloplegic to their eyes. To examine more directly the influence of lens changes on intraocular forces, Young (1981) examined pressure changes in the eyes of accommodating monkeys and performed ultrasonic studies on humans while they changed their focus. He found that intense accommodation caused an increase in the pressure in the vitreous chamber of the eye and suggested that a sustained increase in such pressure may lead to an elongation in chamber depth; an increase in the axial length of the eye.

The only physiological factor Baldwin (1964) found to be consistently correlated with refractive error was the axial length of the eye. Studies of rabbit sclera (Ku & Greene, 1981) produced evidence that high intraocular pressure produced deformation of the sclera and increased the eye's axial length. Coleman and Trokel (1969) speculate that the constant squinting of uncorrected myopes attempting to increase their acuity may produce intraocular forces that can stress the ocular coats eventually leading to enlargement of the vitreous chamber of the eye. One reason hard contact

lenses inhibit the progression of myopia more than their soft counterparts may be due to their inhibitory influence on eyeball elongation (Stone, 1973; Kerns, 1981).

A summary of the near-work argument, then, is that increased accommodation results in a tensing of muscles in or around the eye, increasing intraocular pressure, eventually making the eye permanently myopic. Even one arguing for an environmental cause of myopia should not disregard the influence heredity might play by introducing a predisposition to axial elongation (Honmura, 1968). In addition, Coleman and Trokel (1969) were able to directly measure intraocular pressure of a human in conjunction with surgery and they found that even normal activities such as blinking caused extremely high intraocular pressure, much higher than had been previously realized. This uncertainty that accommodative muscular tension in humans significantly increases intraocular pressure coupled with a lack of understanding of how it permanently modifies spherical refraction leaves the use-abuse theory on unstable ground. The biological theory, however, cannot account for a genetic determinant of myopia among the better educated, Alaskan Eskimo children, or residents of industrialized and urban areas. It seems that the relative importance of heredity, near work, diet, metabolic factors, and psychological factors in the etiology of myopia are still uncertain (Birnbaum, 1981).

Treatment of Myopia

Supporters of the use-abuse theory raise the possibility that at least some myopia may be preventable by avoiding near work. Such a view is directly behavioral in nature, although it is usually not labeled as such.

Accordingly, control of environmental factors, particularly reducing the need for close focusing, may be effective in preventing or reducing myopia (Roberts & Banford, 1967; Kelly, Chatfield, & Tustin, 1975; Oakley & Young, 1975).

Ricci and Collins (1981) justify their training of myopes by reevaluating the nearsighted malady and state, "Myopia...is reconceptualized behaviorally as a disorder in which distant stimuli no longer exert appropriate stimulus control" (p. 441). Birnbaum (1981) suggests vision training as a regimen for the clinical management of myopia to facilitate development of adequate accommodative skills and freedom of action between the systems of accommodation and convergence. By addressing the task of improving nearsightedness with behavioral training, one is accepting that effective vision is a function of learned visual and perceptual habits in a healthy organism as well as the optical characteristics of the eye. Vision is psychologically as well as physically mediated.

The suggestion that the discipline of psychology might have relevance for those attempting to reduce myopia is no surprise to many. Several optometrists (Lanyon & Giddings, 1974) have observed patients who perform far better in the real world than their clinically assessed acuity would allow. An example might be a basketball player who is myopic but can exhibit superior performance on the court without corrective lenses. Bates (1920) and many of his followers (Peppard, 1940; Huxley, 1942; Corbett, 1957) claimed to observe improvements in the visual acuity of patients after training. Their methods, unique at the time, included rest of the mind and the eyes, recalling pleasing events, reading progressively smaller and smaller print, and other exercises which are similar to some present-day behavioral

therapy techniques. Lastly, the conditionability of physiological functions has been established (Bandura, 1969). Autonomic functions such as blood pressure, heart rate, body temperature, and sweat production have proven amenable to operant conditioning (Snyder & Noble, 1968; Miller, 1969). Thus, clinical-behavioral precedent exists for exploring the role that conditioning might play in the modification of myopic acuity decrement. The contribution that psychology might make to the understanding of myopia led Lanyon and Giddings (1974) to state:

> Whatever the precise mechanism of myopia turns out to be, it seems clear that it will be aptly described as a behavioral-physiological disorder, and that research of a psychological nature will play an increasingly important part in its understanding and prevention. (p. 280)

Mechanisms that Facilitate Acuity

Many of the gross fundamental physical processes involved in acuity have been recognized for decades, but more recently investigators have focused on the mechanism's interaction and amenability to training. Our knowledge of the roles that accommodation, pupil response, and stimulus characteristics play in acuity is expanding every day. The autonomic nervous system, volitional effort, reinforcement, and motivation have only recently been incorporated into vision research. The more established physiologically based models of accommodation (Westheimer, 1965; Toates, 1972) are being rethought based on these and other previously unexamined physiological and psychological influences on visual processing and interpretation. Although most of the basic elements in acuity remain founded, discoveries in some areas have caused a broadening and

refocusing of research efforts to pinpoint mechanisms that facilitate acuity.

Accommodation

The most obvious physiological factor that influences acuity is the accommodative state of the eye. When the untrained eye looks into either a dark or luminous empty field, it exhibits a phenomenon known as empty-field myopia (Morgan, 1957), also referred to as the resting state of the eye (Toates, 1970). It is the lack of a visual stimulus and, some suggest more specifically, the absence of visual contrast that results in misaccommodation, an inappropriate thickening of the lens (Westheimer, 1957). This resting state corresponds to an average accommodative response of 1.5 D (Leibowitz & Owens, 1978), proper accommodation for an object placed at 2/3 m.

Subjects will thus always be able to accommodate to targets at their respective dark focus (Owens, 1980). In fact, the best match between subject accommodative state and actual stimulus location occurs when the stimulus is detailed, luminance is high, and it is presented at the subject's dark focus or about arm's reach (Leibowitz & Owens,1978). The amount of positive or negative accommodation of the lens in or out from the resting position is influenced by the distance a stimulus is from an observer mediated by the spatial frequencies, orientation, retinal locus, scene luminance, and texture (Campbell & Westheimer, 1959). Accommodation does not, however, appear to be purely reflexive nor unmediated by volitional effort (Campbell, 1959).

The previously mentioned empty-field myopia takes 1 to 2 minutes to fully develop, depending on the distance to which the eye was last

accommodated, and sometimes on the "will" of the observer. "Thinking *near" or "thinking far" can influence the rapidity* of the drift toward the eventual resting state (Malmstrom & Randle, 1976). Using natural backgrounds and surroundings outside of a laboratory environment, Owens (1980) found subjects could identify gratings of lesser contrast if they exerted effort. Likewise, Margach (cited by Friedman, 1981) found accommodative response linked to the cognitive act of trying to identify visual objects. Subjects, after training with appropriate feedback techniques, could even disregard a stimulus and voluntarily control their accommodative response, essentially ignoring the stimulus field (Randle, 1970; Provine & Enoch, 1975). Extreme efforts to see can, however, result in overaccommodation and a temporary increase in myopia (Owens & Leibowitz, 1976).

Pupil Size and Blur Interpretation

The ability of an observer to resolve small targets is influenced not only by their accommodative state but also by pupil size. When the pupil's diameter is less than 2.5 mm, the imaging characteristics of the eye are purely diffraction limited (Leibowitz, 1952), and the depth of focus approaches a maximum. Grating acuity is maximized when the natural pupil is 2-5 mm (Leibowitz, 1952) and sensitivity to contrast is highest with such an intermediate pupil diameter (Campbell & Green, 1965). Although the retinal image might be reduced by low illumination when the pupil is small, the increase in retinal illumination when the pupil is large is outweighed by the detrimental influence of spherical and chromatic aberration. Trachtman (1987) found that a reduction in pupil size alone may improve acuity although accommodation remains unchanged.

One means of partialling out the influence of retinal image quality is accomplished by placing an artificial pupil before the eye. Such an artificial or simulated pupil can increase the depth of focus to such an extent that the influence of accommodative changes is greatly reduced (Ripps, Chin, Siegel, & Breinin, 1962). With a small pupil, or small artificial pupil, a large error in accommodation is necessary to produce a given amount of blur (Toates, 1970). Complicating any direct relationship between blur and accommodation change, Ogle (1961, 1962) reported that blur or defocus affected visual sensitivity more for small than for large targets. One would likely be able to recognize large objects with great degrees of blur but near-threshold visual extents with far less blur. Any interaction between accommodation and blur may be restricted to stimuli of limited visual extent.

Stark and Takahashi (1965) proposed an inverted U-shaped functional relationship between blur and accommodation. When blur is slight, increasing its magnitude increases the viewer's attempt to change accommodation. At extreme levels of blur, small increases in blur result in no corresponding increase in effort to change accommodation. Some have suggested that one benefit of vision training might be a heightened subjective sensitivity to blur. The resultant superior blur interpretation may be due to a more practiced blur-accommodation loop (Woods, 1946; Fenton, Collins, Burkett, & Amato, 1981; Collins, Epstein, & Gil, 1982; Collins, Gil, & Ricci, 1982; Gil & Collins, 1982).

Autonomic Nervous System

Recent studies have provided evidence that supports both the influence of the autonomic nervous system on accommodation (Gawron, 1983;

Gilmartin & Hogan, 1985; Stepnens, 1985) and other nonoptical determinants of accommodative responses. Morgan's (1944) electrical stimulation of the sympathetic nervous system produced a 1.5 D negative or outward shift in accommodation. When Giddings and Lanyon (1971) studied the pairing of anxiety-arousing events with in-focus visual perception, they found "stressed" myopes showed a trend toward an increase in refractive error. Toates (1972) found overaccommodation is the stimulus for the sympathetic division and underaccommodation for the parasympathetic division. The equilibrium established between the sympathetic and parasympathetic systems seems to play a role in the biological hysteresis earlier described as empty-field myopia or resting accommodation (Randle, 1975).

Relaxation

For nearly 100 years, the psychological approach to myopia has recognized the nonoptical role of the autonomic nervous system through its emphasis on relaxation. At the turn of the century, Bates (1920) was professing that vision problems were the result of stress, trying too hard to see, and improperly channeling our field of concentration. A follower of his teachings, Corbett (1957) states, "Many persons have good vision but their eyes do not behave properly. Such poor behavior will eventually impair their sight, no matter how good it is fundamentally" (p. 31).

Recently, investigators have continued stressing relaxation by subjects participating in vision studies as well as finding evidence for its influence in performance. Participants in Friedman's vision training program for myopia management (1981) were told to take a more passive or "defensive" viewing

style as opposed to their natural "offensive" visual style characterized by active, often intense, information collection. Prior to their vision training sessions, Giddings and Lanyon (1974) seated their subjects in an overstuffed chair, made sure they were comfortable, and played an 11-minute tape recording of physical relaxation instructions. Their hope was that general relaxation and an emphasis on distant vision would allow subjects to experience and later replicate the "feelings" associated with accommodative relaxation (Berens, Girard, Fonda, & Sells, 1957).

Similarly, hypnotherapy has been incorporated into vision improvement programs (Copeland, 1967; Lupica, 1976) and Kelley (1962) found refractive changes in myopes under hypnosis who achieved clearer vision. When Trachtman used behavioral training to reduce myopia he reported subjects experienced with yoga, meditation, or other relaxation techniques progressed faster (Van Horn, 1984). It seems important that subjects not only be educated in skills in accommodative relaxation (Birnbaum, 1981) but that certain visual functions may be modifiable by behavioral means.

Vision Improvement Through Operant Conditioning

The physiological mechanisms of accommodation, pupil size, and the autonomic nervous system along with behavioral mediators have been investigated in vision training paradigms. There is still disagreement as to which, if any, of these mechanisms facilitate improvement. There remain disbelievers regarding the value of vision training. In 1957, Berens et al. summarized the feelings of many when they stated, "Although the effects of eye exercises and visual training on visual functions have been investigated, there have been virtually no studies in which relevant factors

have been adequately controlled" (p. 25). Thirty years later, we still don't know the mechanisms that facilitate behaviorally trained visual acuity improvement (Gallaway, Pearl, Winkelstein, & Scheiman,1987).

Relatively few eye care practitioners (optometrists, ophthalmologists, etc.) have reported clinical reduction of myopia as a result of training programs (Berens et al., 1957; Harris, 1974; Nolan, 1974). In Woods' study (1946), 60 percent of the myopes showed significant acuity improvement through training, with no reduction in refractively measured myopia. He attributed the improvement to experience in correct interpretation of a blurred visual image. Gibson (1953) proposed that trained subjects show an increase in acuity as a result of adaptation to the procedure or perceptual learning. Goss (1982), an optometrist, claims there does not seem to be any effective treatment for myopia other than corrective lenses. It may be that optometrists who do not specialize in visual training can not detect changes in normal vision after training because their standard clinical measurements may be inappropriate or lack the sensitivity to detect training-induced changes (Goodson & Rahe, 1981). Opposed to these skeptics are many investigators who have found both subjectively reported qualitative and significant quantitative improvements as a result of vision training.

Despite the disagreement as to its usefulness or rendering mechanisms, vision training has been used for decades. As early as World War II, combat pilots received visual training in recognition with tachistoscopically flashed profiles and silhouettes of enemy and allied aircraft (Renshaw, 1945; Woods, 1946). Provine and Enoch (1975) trained subjects to use internal performance criteria independent of visual feedback to initiate and maintain an accommodative response. Several investigators have demonstrated the

presence of voluntary accommodation in a variety of tasks (Carr & Allen, 1906; Carr, 1907; Sisson, 1938; Westheimer, 1957; Randle, 1970; Cornsweet & Crane, 1970, 1973; Trachtman, 1978). Roscoe and Couchman (1987) found that subjects displayed improvement in their visual acuity, contrast sensitivity, and flash target resolution by exercising acquired volitional accommodation. Giddings and Lanyon (1974) found an average of 0.25 D less myopia in subjects who participated in visual acuity training.

Biofeedback

One popular approach to vision training is to introduce biofeedback into the visual process (Randle, 1970, 1985; Cornsweet & Crane, 1970, 1973; Trachtman, 1978, 1987). In a general sense, biofeedback is the production of an awareness of a bodily function or process of which a person would normally not be aware. Sission (1938) explained biofeedback as a procedure which seems similar to that involved in learning to wiggle one's ears; getting the "feel" of the muscular adjustments involved so that they can be duplicated at will. The goal of the feedback in the case of vision training is to place the mechanisms of perception under voluntary control. Specifically applicable to myopes, biofeedback, proponents claim, helps observers relax accommodation, thus facilitating more distant visual acuity.

It was the perfection of the covert servo-controlled tracking optometer (Cornsweet & Crane, 1970) that made the near-instantaneous feedback of monocular accommodative state possible. Randle (1970) was the first to use biofeedback in volitional accommodation training. He used a focus training technique that translated the Cornsweet and Crane infrared-optometer measures of accommodation into auditory tones that reflected the instantaneous refractive state of the eye. While an observer monocularly

tracked a target in and out in optical distance, the pitch of a tone increased or decreased in accordance with accommodative state. Once the association was established, the trained observer could voluntarily control the pitch of the tone even though the visual stimulus had been removed.

Trachtman (1978) similarly trained a myope for seven sessions totaling 34 minutes resulting in an improvement in unaided binocular visual acuity from 20/50 to 20/30. In 1985, Randle taught volitional focus control to myopic subjects who subsequently showed an extension of their resting focus and an average acuity improvement from about 20/75 to about 20/50. These results demonstrate the effectiveness of biofeedback in reducing myopia and increasing distant acuity by training voluntary control of accommodation. They do not, however, clarify how other physiological and psychological mechanisms may affect acuity improvement.

Feedback obviously performs an important role in learning accommodative control. Cornsweet and Crane (1973) noted the importance of the naturalness of the feedback:

> Subjects may require only a short time to learn to use any given cue for accommodation when the feedback is natural (that is, a change in actual blur), but may require considerable practice to learn the different skill of controlling accommodation when the feedback that they must use is artificial, and when the feedback is erroneous in the sense that the visual blur does not actually change when accommodation does. (p. 714)

This reinforces the role of blur interpretation in improving myopic acuity (Woods, 1946; Hildreth, Meinberg, Milder, Post, & Sanders, 1947), a tenet of Trachtman's (1987) model of the mechanism for improving acuity. If volitional accommodation is the mechanism of improvement, then better

visual acuity should not take place without an accompanying change in refractive error. Subjects who demonstrate acuity improvement after training should thus display some change in their refractive error. The measured refractive error of such subjects did not reflect changes from pretraining measurement (Marg, 1952; Balliet, Clay & Blood, 1982); clearer vision was not due to an accommodation change.

Gallaway et al. (1987) found one of their control subjects displayed a great deal of acuity improvement without biofeedback training, and they also found no refractive error changes in biofeedback training subjects. This led them to question if improvement in acuity was due solely to the biofeedback training or was facilitated by learning effects brought about by repeated measuring of visual acuity. The utility of biofeedback has been open to criticism based on these incomplete explanations of the roles that practiced blur interpretation, accommodative changes, reduction in myopic refractive errors, and training artifacts play in acuity improvement.

Fading and Feedback

In 1974, Giddings and Lanyon took a different approach to training better acuity. They exposed subjects to visual stimuli that were made progressively smaller, a process they called "fading". Subjects given "praise" contingent upon correct identification were able to identify smaller targets after the training; if they received noncontingent feedback or no praise they showed less improvement. Epstein, Collins, Hannay, and Looney (1978) modified the fading to entail moving stimuli farther away and renamed the contingent praise "feedback". After their subjects refrained from near work for a few minutes, they were given feedback as they

identified stimulus letters that were moved farther away when correctly recognized. Subjects trained with the fading and feedback techniques displayed significantly greater improvement in visual acuity than matched control subjects.

In a subsequent investigation, Collins, Epstein, and Hannay (1981) assigned matched-acuity myopes to one of five groups: fading and feedback, fading, feedback, yoked, and no treatment. The fading distances and feedback for yoked subjects depended exclusively on their matched fading and feedback counterpart. That is, neither fading of their stimulus letters nor their feedback was influenced by their performance; if their counterpart correctly identified a letter and was given positive verbal feedback on a given trial, they too received positive feedback on that same trial, without regard to their true performance. After 15 one-hour training sessions, those trained with fading and feedback or fading only exhibited significantly more visual acuity improvement than those receiving no treatment.

The generalizability of fading and feedback exercises has been tested in two studies using training stimuli that were substantially different from testing stimuli. Gil and Collins (1982) found subjects trained with fading video game presentations subsequently displayed significant improvements in acuity assessed with letter stimuli. Collins et al. (1982) report subjects trained with fading letter stimuli likewise displayed facilitation in facial discrimination and small object identification ability. Distant video game performance was not improved, however.

Mechanisms

These findings suggest that fading is the most important part of this training technique although contingent feedback and fading may be slightly more effective than fading alone. In an attempt to explain these findings, Collins et al. (1981, p. 700) state that, "The particular physiological mechanism responsible for the changes in acuity...can only be postulated." More importantly, the mechanisms responsible for the changes in acuity may not be only physiological, they may be behaviorally influenced as well. Fenton et al. (1981) hypothesize two mechanisms of facilitation:

> First, the improvements in acuity may be the result of increased ability to discriminate distant stimuli by improvements in the ability to recognize blurred objects. Second, improvements may be the result of changes in the optical components of the eye so that the stimuli are more clear and distinct. (p. 1)

All the mechanisms previously suggested as possible mediators of acuity improvement with biofeedback may also be at work in the fading and feedback training approach; blur interpretation, accommodation changes, training artifacts, and, in addition, motivation.

Blur Interpretation

An attempt was made to assess what role blur discriminability may play in the fading and feedback improvement by testing subjects with letter stimuli after training with fading video-game displays (Gil & Collins, 1982). Although the researchers made the argument that improvement in the untrained condition letter identification task tempered the role of blur interpretation, it is also possible that blur discrimination in one task facilitated

biur discrimination in the other.

Accommodation

Whereas learned control of accommodation is postulated as the mechanism of facilitation in the Collins et al. (1981) study, no measure of accommodation nor measures of refractive error were taken. A subsequent attempt to measure refraction during fading was performed (Blount, Collins, & Gil, 1981) but it failed to show a reduction in refractive error expected to accompany volitional accommodation.

Training Artifacts

Finally, Collins et al. (1981) suggested that there is no evidence of a nonspecific training artifact because there is no significant performance improvement difference between the no-treatment control and the yoked treatment group. It might also be that yoked treatment group members lost interest in attempting to correctly identify letters as they likely recognized that what they said did not matter; they were told they were right or wrong based on a matched individual's performance. The possible roles of feedback, motivation, and training effects need further clarification.

Feedback

Some participants in the fading and feedback training received almost immediate nonvisual feedback, being told if their responses were correct or incorrect. Collins et al. (1981) state that it was their feedback-and-fading and feedback-without-fading groups which received such performance assessment. The fading-only group, however, received indirect feedback as

the letter stimuli were either moved farther away from the subjects if they correctly identified 10 consecutive items or moved closer if subjects failed to correctly identify 10 consecutive items (from a series of 50). One might suspect that at some point (possibly very early) in the 15-session experiment subjects discovered the correlation between performance and stimulus movement; e.g., "If the targets were fairly clear and the experimenter moved them back, I must have gotten them right."

Although feedback might be postulated to be a motivator, too much negative feedback or the realization that one's performance has no bearing on the resultant feedback can certainly be discouraging. In explaining a methodological problem they had with their feedback-only group, Collins et al. state, "Since the terminal distance of the subject's matched counterpart in the fading and feedback group was chosen as the feedback distance, this distance was at times too far for some subjects (resulting in little positive feedback" (p. 700). Similarly, members of the yoked group were not only given incorrect feedback, but they also probably deduced that their report did not matter. At some point when they saw a clear, uniquely shaped letter (e.g., T, I, or L) and were told they were wrong, they likely gave up. Most significantly, members of either the feedback-only or yoked groups might not only have given up during the training phase, but also during their subsequent posttesting assessment used to measure training-induced acuity improvement.

Motivation

Motivation and reinforcement have been cited as critical components in previous visual acuity training. Threshold measurements are influenced by

the general attitude that subjects adopt (Blackwell, 1952) and reinforcement in acuity training has proven to contribute to improvement (Selis & Fixott, 1957; Giddings & Lanyon, 1974). Birnbaum (1981) noted that visual acuity training commonly resulted in unaided acuity changes for myopes when motivation was high. Significant increases in acuity with accompanying decreases in refractive error have been noted as occurring in subjects receiving training with contingent approval (Giddings & Lanyon, 1974). Berens et al. (1957) achieved significant acuity improvement and refractive error reduction with a tachistoscopic training program but all subjects assigned to the treatment group were judged "highly motivated" and those assigned to the control group were judged "poorly motivated".

Some people who seek training in their visual performance or, specifically, improvement in their clinically chart-assessed acuity are motivated to improve their vision so that they may pass an eye exam. Such passage may allow them to attend a service academy, commence an employment training program, obtain or maintain a flying certification, enter police or fire department training, or shed lenses that they find uncomfortable, unattractive, or hard to wear under certain circumstances. People with these goals probably do not need as much encouragement, reinforcement, or extrinsic motivation as others who have similar vision decrements but who lack an intrinsic desire of equal strength. Further research is needed using a positive reinforcement contingency (Giddings & Lanyon, 1974) and objective measures or ratings of incentive to assess the roles of feedback and motivation in vision training (Friedman, 1981).

Training Candidate Selection

Not only has there been disagreement as to the mechanisms responsible for vision acuity improvement, but researchers also disagree as to who will benefit most rapidly from vision training. Berman et al. (1985) claim that persons with the most impairment exhibit more rapid increases in acuity enhancement. Friedman (1981) feels that those who first experience myopia in their late teens, 20's, or 30's and have less than a -2.25 D refractive error are most likely to achieve and maintain improvement. Birnbaum (1981) suggests vision training as a preventive measure, having the greatest chance of halting or slowing myopic progression when patients display early signs of nearsightedness. Finally, Sloane, Dunphy, and Iannsons (1948) advise their fellow vision training colleagues that if one is interested in selecting those patients most likely to benefit from training, "The best results may be anticipated in a patient whose visual acuity is found to be less than one would expect from a determination of his refractive error" (p. 112).

Training Pitfalls

Even when vision training does not result in statistically significant improvements, its proponents have suggestions as to common pitfalls. The training technique or duration was, possibly, inadequate or subject selection was inappropriate. More sessions, longer sessions, better preparatory relaxation, or a longer total effort might be needed to yield results. Both intrinsic and extrinsic motivation might be lacking and limit facilitation. Regardless of measurable improvement, the training might still improve

visual performance in ways not linked to acuity measures. Goodson and Rahe (1981) found that the pilot subjects in their vision training study showed no significant acuity improvement but most felt that, as a result of their training participation, they had begun to use their eyes more effectively, had less fatigue, focused faster, and had more confidence in their visual performance.

Research Directions

Both extravagant claims and forthright condemnation of visual acuity training have been based on an incomplete understanding of the physiological and psychological mechanisms involved in acuity enhancement. Although there is little agreement regarding the etiology and the exact basis of myopia, improved visual acuity has been achieved using behavioral training techniques. Whether it is physiological changes, modified processing, motivation, or simply practice, behavioral training seems to improve visual acuity in some myopes. We do not yet know, however, which mechanisms facilitate a change in acuity or to what extent they do so. There is a definite need for further investigation of both the utility of vision training and the mechanisms that play roles in subsequent acuity improvement.

This investigation incorporated parallel experiments to further clarify the roles that fading and feedback play in vision training and to what degree training in acuity mechanisms facilitates acuity enhancement. Experiment One was designed to help identify treatment components critical to operantly trained acuity enhancement. Eight acuity measures were incorporated to allow assessment of generalizability of enhancement from stimuli used in

treatment to nontreated stimuli. In addition, these measures allowed quantification of the role that blur interpretation and pupil size play in acuity enhancement. Experiment Two was designed to help substantiate the degree of acuity enhancement facilitated by training in pupillary control, blur interpretation, and accommodative flexibility. Finally, the combined pretraining acuities of all subjects were used to compare Snellen letter acuities with contrast sensitivity measurements. The identification of essential training regimens and the amenability of some facets of acuity to training helped demonstrate the viability of acuity training.

EXPERIMENT ONE

Method

This investigation consisted of two experiments aimed at pinpointing mechanisms that facilitate acuity enhancement. The goal of experiment one was to do the following:

- Ascertain any differential effects of training with stimulus fading and/or performance feedback on improvement in Snellen letter recognition acuity.
- Assess the generalization from treatment to nontreatment stimuli and from high-contrast training to low-contrast acuity.
- Attempt to develop an equation that accounts for changes in acuity based on blur interpretation, pupil size, and training:

$$\Delta \text{ acuity} = \Delta \text{ blur interp} + \Delta \text{ pupil size} + \text{start acuity} + \text{tng type}$$

where

Δ acuity = change in recognition acuity

Δ blur interp = measurable change in ability to recognize blurred stimuli

Δ pupil size = change in average pupil diameter

start acuity = initial (pretraining) recognition acuity

tng type = training method (fading and feedback, feedback only, etc.).

- Confirm that any acuity enhancement is relatively enduring.

Subjects / Design

Thirty-six myopic U.S. Air Force Academy freshmen and sophomores (ages 19-23) were equally divided into six groups; four treatment groups, one nontreatment group, and one minimal-contact control group. Members of each group received training with their respective regimens: Fading and feedback, fading and no verbal feedback, fading and no feedback, feedback and no fading, and no treatment. Nontreatment group members participated in an equal number and duration of sessions as did treatment group members but received no treatment. Control group members participated in both fewer and shorter sessions. Treatment was accomplished with high-contrast Tumbling E stimuli. Dependent measures included high-contrast Tumbling E acuity and nontreated Snellen letter acuity, Ortho-Rater checkerboard acuity, low-contrast Tumbling E acuity, contrast sensitivity, defocused Tumbling E and letter tolerances, and pupil size.

Subjects were matched so that initially each group had the same distribution of subject Snellen letter acuities; one 20/25, one 20/30, one 20/40, one 20/50, one 20/70, and one 20/100. Each participant was a regular wearer of prescription glasses or soft contact lenses (no hard contact lens wearers took part in this study). There was no need for subjects to remove their lenses other than during the daily one-hour sessions. Participation was voluntary and permission was granted to conduct this research at the Academy with cadets.

Apparatus

Snellen Charts

Standard Armed Forces Clinical Visual Acuity Test Charts were used to measure acuity both before and after training. Memorization of charts was avoided by alternating charts through selection from a library of nine.

Bausch and Lomb Modified Ortho-Rater

The Modified Ortho-Rater was a compact, portable, self-contained stereoscope used to measure binocular distant acuity with non-letter stimuli. These stimuli were large squares divided into nine smaller squares with the corner and center areas serving as possible targets (see Figure 2). One target area in each checkerboard was filled with individual squares of such sizes as to subtend visual angles equivalent to Snellen ratings of

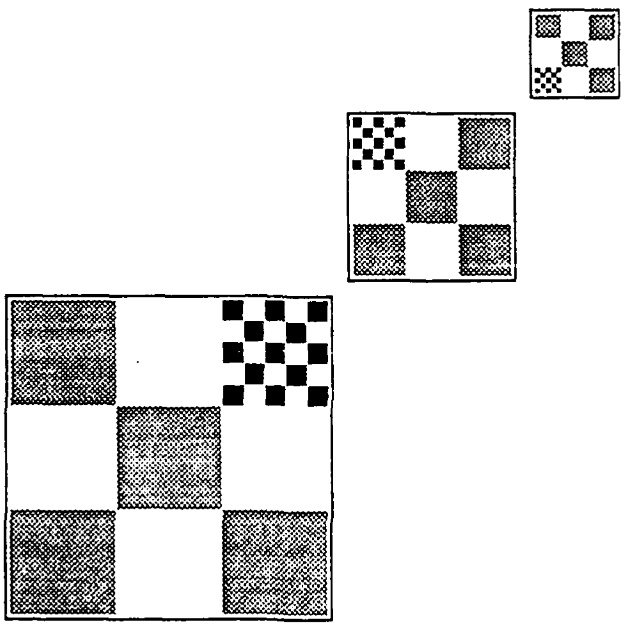

Figure 2. Modified Ortho-Rater checkerboard stimuli.

20/200 to 20/17 in 12 graduated steps. The Ortho-Rater allowed assessment of non-letter acuity based on the smallest visual angle that the subject could discriminate.

Training Apparatus

Both low- and high-contrast Tumbling E's were presented on a monochrome Apple® Macintosh™ Plus computer screen. Four E's appeared on the screen when subjects could recognize 10 mm or 20 mm E's at more than 300 cm (corresponding to acuities of better than 20/40 and 20/80, respectively). If acuity was less than 20/80, only two 30 mm or 40 mm E's appeared on the screen. The E's were separated by one character width and were randomly presented in one of four orientations. The computer was mounted on a wheeled moveable platform that was slid along a 610-cm (20-ft) rail calibrated in centimeters. A black shield mounted to the front of the moveable platform allowed only the computer screen to be seen through an opening 180 mm x 140 mm. The experimenter clicked a mouse on the back of the platform to display the E's and read stimulus distances by referencing the platform position along the rail.

Contrast Sensitivity

A VISTECH Consultants, Inc.[1] Model 6500 chart (1985) was used to assess participant contrast sensitivity. The chart presented sine-wave grating patches at calibrated contrast levels to subjects at a distance of 305 cm (10 ft). The gratings appeared straight up-and-down or rotated

[1]VISTECH Consultants, Inc. 1372 N. Fairfield Rd. Dayton, OH 45432

between 10 and 30 degrees clockwise or counterclockwise (rightward or leftward, respectively). Five spatial frequencies were represented on the chart (1.5, 3.0, 6.0, 12.0, and 18.0 cpd) and each was presented at nine levels of contrast. The 9 x 5 chart matrix presented a single grating frequency on each row that varied, from left to right, from high- to low-contrast.

Blur Assessment

Participants viewed high-contrast individually presented rear-projected Tumbling E's and Snellen-type letters at 3/4 m (1.5 D), the average far point. Stimuli subtended a visual angle commensurate with each subject's 610 cm (20 ft) 100 percent Snellen acuity threshold. Both the E orientations and letters were randomized but consistent across trials between groups. The stimuli were initially displayed 3 D out-of-focus and the subject brought them closer to in-focus with 1/4 D step adjustments. Once the orientation of each E was properly reported or the letter identified, the distance between the lens and stimulus was measured. The letter projections with these lens displacements were subjectively compared by two observers to photographed letters with 1/4 D incremental defocus. For precision, the lens displacement distances were used for statistical analyses; however, for clarity, the subjectively determined equivalent amount of defocus in diopters that still allowed Tumbling E resolution or Snellen letter recognition are occasionally reported.

Pupil Diameter

A Whittaker Corporation Series 800 T.V. Pupillometer with strip chart measured the subject's left-eye pupil size at a rate of 60 times per second. Pupillometer measurement ranged from 0 to 10 mm and accuracy was better than 1 percent. Its video camera was offset enough laterally to allow pupillary readings during binocular stimulus viewing.

Television Viewing

A color television mounted on a moveable platform similar to that of the testing apparatus allowed the experimenter to move a video image farther from the observer without interfering with active viewing. Recorded video tapes and a video player allowed standardization of distant television presentations.

Procedures

Both treatment group and nontreatment group subjects participated in five consecutive-day 1-hour sessions. Minimal-contact control group subjects participated in only two 1-hour sessions separated by 96 hours (comparable to days 1 and 5 of the other subjects' training). No participants were allowed to squint during any of the acuity assessment or training. During the first 15 minutes of each session participants watched a distant television with their glasses or soft contact lenses removed. No near visual focusing was allowed during this accommodative relaxation period.

On the first day of participation, regardless of group assignment, five initial measurements were taken following the 15-minute distant-viewing

relaxation period. First, Snellen acuity was assessed. Participants read the chart from top to bottom (20/200 to 20/10) from a distance of 6.1 m (20 ft) until they correctly identified less than 100 percent of the letters on a given line. Next, the resolution distance for both high- and low-contrast Tumbling E's was measured. Subjects reported the orientations of E's that were made increasingly smaller until reporting accuracy was less than 100 percent. Participants then identified the locations of progressively smaller and smaller Ortho-Rater checkerboard projections. Finally, contrast sensitivity was measured. Subjects attempted to resolve the gratings in each chart patch and reported the orientations across each frequency-specific row from left-to-right. The first three of these measures were repeated at the beginning of each day for treatment and nontreatment group members.

Each treatment group subject received 30 minutes of group-specific training. The initial distance of training apparatus stimulus presentation was estimated from the Snellen acuity measured at the beginning of each session. Each subject's Snellen acuity and both high- and low-contrast Tumbling E acuity was again measured subsequent to training. In addition, blur tolerance was measured by having subjects attempt to resolve the orientations of 7 Tumbling E's and try to identify 10 letters presented at the average far point. Finally, the size of the left pupil was measured for each subject while viewing a Snellen Chart. Average pupil size over a 1-minute time period was calculated. Postsession measurements were identical for nontreatment group members.

Regardless of group assignment, the same five measurements made on the first day were repeated prior to the fifth-session termination. In addition to these Snellen, Tumbling E, Ortho-Rater, and contrast sensitivity

assessments, blur tolerance and pupil size were also measured for each subject.

Delayed retest assessments were made on six subjects without interim measurements or treatment. Two subjects were tested 27 days after, two 39 days after, and two 45 days after their fifth day of participation. The retest measurements were the same as those used on the fifth day of participation. Only a 15-minute distant television viewing relaxation period preceded each subject's retesting.

Treatment Group Procedures

Fading-and-feedback treatment group. Members of this group were told that their responses were "correct" if they accurately identified the orientations of all the Tumbling E's. When responses were correct, the next E's were presented 5 cm farther from the observer. If any of the orientations were misidentified, the orientations of all the E's on the screen were reported to the subject as feedback, e.g., "Up, up, left, right." The next E's following any misidentification were presented 3 cm closer to the subject. The retreat and advance distances were unequal to avoid symmetric bracketing of a threshold resulting in repeated presentations at exactly the same distances.

Fading-with-no-verbal-feedback treatment group. Movements of the Tumbling E's were identical to those for the fading and feedback group members, 5 cm farther when correct and 3 cm nearer when incorrect. Neither verbal report of correctness nor orientations were given to the subject.

Fading-with-no-feedback treatment group. Following each report, the stimuli were moved grossly toward the subject and then away, beyond the trial-specific distance before being positioned for the subsequent trial; e.g., 20 cm toward the subject, then 40 cm away from the subject, then 15 cm toward the subject and stopped 5 cm beyond the previous presentation position. These large movements were made in an attempt to prevent subjects from recognizing how presentation distances varied. Resultant presentation distances of the Tumbling E's were identical to those for both the fading-and-feedback group members and the fading-with-no-verbal-feedback group members. Neither verbal report of correctness nor orientations was given to the subject.

Feedback-only treatment group. The accuracy of Tumbling E orientation identifications was reported to these group members in the same manner as to fading-and-feedback group members. The E's were moved farther from the subject until there was a misidentification and then remained at that location for the duration of that training session.

Nontreatment Group Procedures

Television-viewing nontreatment group. Members of this group viewed video-taped television for the approximate 30-minute duration of the training session. The initial distance of the screen from the observer was that at which they reported the screen to be slightly blurry. The television was then moved farther or closer to the observer during viewing in accordance with the positions of the Tumbling E's displayed to a paired counterpart subject in the fading and feedback group with a maximum distance of 610 cm (20 ft).

Control group. On both days of participation (separated by 96 hours), each subject's Snellen letter acuity, high- and low-contrast Tumbling E acuities, Ortho-Rater nonletter acuity, contrast sensitivity, blur tolerance, and pupil size were measured once following their 15 minutes of distant television viewing relaxation.

Results and Discussion

The mean pre- and fifth-day posttraining performances by group assignments are presented in Table 1. Table 2 presents a summary of the day-5 versus day-1 directional changes by group members on each of the eight performance tasks. Snellen letter and Ortho-Rater checkerboard acuities were converted to decimal notation for analysis (e.g., 20/20 equals 1.0). High- and low- contrast Tumbling E performance data represents black-on-white and gray-on-white 10 mm E recognition distances. Contrast sensitivity data reflects the number of VISTECH sine-wave gratings that were resolved. Contrast sensitivity reported in Table 1 is the combined performance of subject's attempts to resolve thirty 1.5, 3.0, 6.0, 12.0 and 18.0 cpd stimuli at varying levels of contrast. Defocused Tumbling E and defocused letter performances represent the diopters of defocus that still allowed subject recognition of stimuli.

Some would argue that the best "control" for comparison purposes is the no-treatment group as they performed everything the treatment group participants did excluding any treatment. However, those proposing operant training as a means to facilitate acuity enhancement might argue that their treated subjects' performances should more appropriately be compared to counterparts measured on only the first and last day of those receiving

Table 1

Mean Pretraining and 5th-Day Posttraining Performance by Training Type

Group	Snellen Acuity Pre	Snellen Acuity Post	Ortho-Rater Acuity Pre	Ortho-Rater Acuity Post	High Contrast E Acuity Pre	High Contrast E Acuity Post
Fading & Feedback	20/52	20/29	20/42	20/30	20/32	20/25
Fading (No Verbal Fdbk)	20/52	20/32	20/44	20/35	20/32	20/25
Fading (No Feedback)	20/52	20/53	20/43	20/40	20/38	20/34
Feedback (No Fading)	20/52	20/40	20/45	20/40	20/37	20/33
No Treatment	20/52	20/39	20/47	20/45	20/34	20/32

Group	Low Contrast E Acuity Pre	Low Contrast E Acuity Post	Contrast Sensitivity Pre	Contrast Sensitivity Post	Defocused E Acuity (D) Pre	Defocused E Acuity (D) Post
Fading & Feedback	20/34	20/28	22.0	23.8	0.74	0.75
Fading (No Verbal Fdbk)	20/35	20/30	17.7	20.2	0.75	0.72
Fading (No Feedback)	20/39	20/35	17.0	20.3	0.70	0.70
Feedback (No Fading)	20/38	20/33	18.7	20.7	0.74	0.72
No Treatment	20/34	20/33	18.8	20.0	0.71	0.74

Group	Defocused Ltr Acuity (D) Pre	Defocused Ltr Acuity (D) Post	Pupil Size (mm) Pre	Pupil Size (mm) Post
Fading & Feedback	0.73	0.78	2.80	2.73
Fading (No Verbal Fdbk)	0.77	0.77	2.70	2.55
Fading (No Feedback)	0.75	0.77	2.70	2.72
Feedback (No Fading)	0.75	0.75	2.60	2.62
No Treatment	0.71	0.76	2.65	2.65

treatment, the first and fifth day in the case of this investigation. It will be shown later that no-treatment members' 5 consecutive-day full-session participation made them more like treatment group subjects than untreated controls. The performance of the first and last day control group subjects, minimally contacted and measured, and their comparative performance with

Table 2

Directional Changes Between Pretraining and 5th-Day Posttraining Performance by Training Type

Group	Snellen Acuity	Ortho-Rater Acuity	High Cont. E Acuity	Low Cont. E Acuity	Contrast Sensi-tivity	E Blur Tolerance	Letter Blur Tolerance	Pupil Size
Fading & Feedback	6 Better - -	5 Better 1 Same -	6 Better - -	6 Better - -	4 Better - 2 Worse	4 Better - 2 Worse	5 Better - 1 Worse	2 Bigger 2 Same 2 Smaller
Fading (No Verbal Fdbk)	5 Better 1 Same -	4 Better 1 Same 1 Worse	5 Better - 1 Worse	5 Better - 1 Worse	4 Better 2 Same -	2 Better 1 Same 3 Worse	3 Better - 3 Worse	2 Bigger - 4 Smaller
Fading (No Feedback)	- 6 Same -	2 Better 4 Same -	6 Better - -	6 Better - -	6 Better - -	4 Better - 2 Worse	4 Better - 2 Worse	2 Bigger 2 Same 2 Smaller
Feedback (No Fading)	3 Better 3 Same -	3 Better 2 Same 1 Worse	6 Better - -	6 Better - -	3 Better 1 Same 2 Worse	2 Better 1 Same 3 Worse	3 Better 1 Same 2 Worse	1 Bigger 3 Same 2 Smaller
No Treatment	4 Better 2 Same -	1 Better 5 Same -	3 Better 1 Same 2 Worse	4 Better 1 Same 1 Worse	4 Better 1 Same 1 Worse	2 Better 1 Same 3 Worse	6 Better - -	1 Bigger 3 Same 2 Smaller

their group counterparts will be addressed later in this section (see Comparison Group to Assess Training Performance Enhancement).

Differential Effects of Training Procedures

Without statistical analysis, a cursory inspection of the data displayed in Tables 1, 2, and A-1 seems to indicate a posttraining performance superiority for those treated with fading and feedback. As compared to the other three treatment and single no-treatment groups, the average fading-and-feedback participant displayed the following:

·Largest Snellen letter acuity change (1.167) and posttraining Snellen letter acuity (20/29);

·Second largest Ortho-Rater checkerboard acuity change (.388) and highest average posttraining Ortho-Rater checkerboard acuity (20/30);

·Largest average high-contrast Tumbling E and low-contrast Tumbling E acuity changes (117.8 mm and 91.7 mm) and the highest average posttraining Tumbling E acuities (20/25 and 20/28);

·Largest change on 12.0 cpd resolution (.667) and second largest change on 18.0 cpd resolution (.50);

·Second largest average defocused Tumbling E resolution change (.213 D) and largest tolerance for Tumbling E blur (.75 D);

·Second largest average defocused letter recognition change (.05 D) and highest average tolerance for letter blur (.78 D).

Figures 3, 4, and 5 display each group's posttraining standardized score changes on all eight of the vision tests. Again, these figures display the fading and feedback group's average superiorities for three of the tasks and second highest changes on four of the remaining five tasks.

The variances of group-specific subject scores were compared by calculating Hartley's maximum F's for each day's performance measurements. Only 1 of 41 variance F's was significant (for Snellen letter recognition change variance: fading-and-feedback versus fading-with-no-feedback, $F(4,4) = 30$, $p<0.05$). Based on these calculations and visual inspection of the data, parametric statistics were deemed appropriate for the analysis.

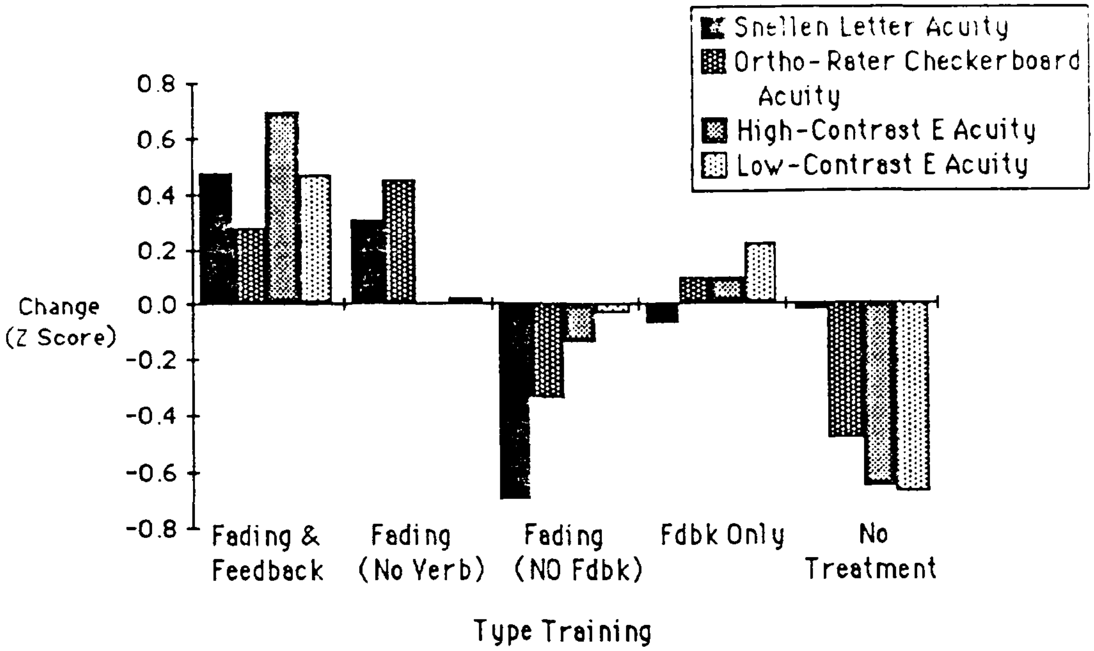

Figure 3. Acuity changes by training type.

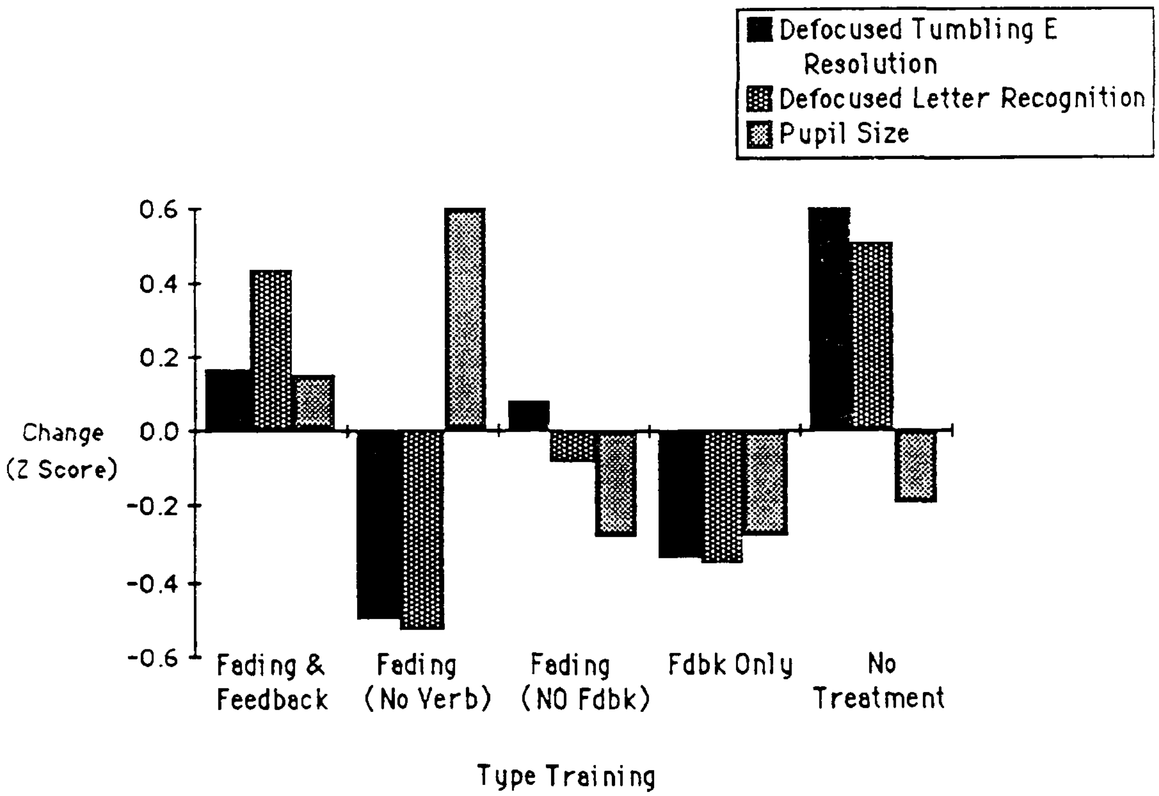

Figure 4. Performance changes by training type.

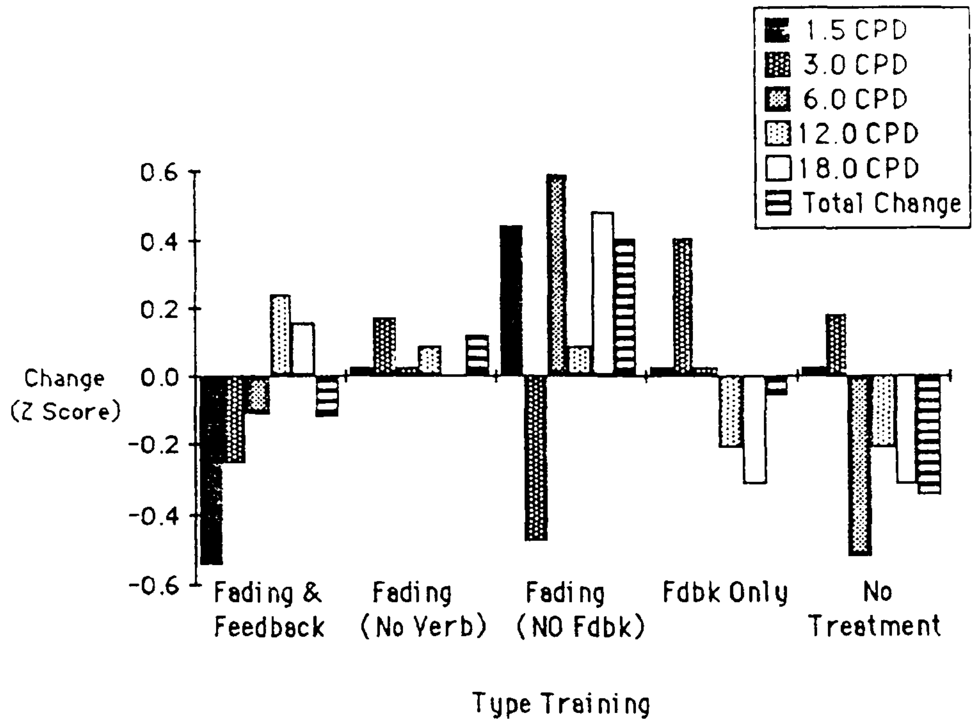

Figure 5. Contrast sensitivity changes by training type.

One-way analyses of variance confirmed no significant group differences between any of the eight performance measurements either prior to treatment or on days one through four. Analysis of fifth-day performance and associated performance changes between days one and five did reveal significant group differences. Less conservative than these Schefeé analyses, a priori planned orthogonal contrasts revealed significantly superior Snellen letter acuity on day-5 for groups receiving fading-and-feedback versus no-treatment, $F(1,25) = 5.92$, $p < 0.010$, and the groups trained with fading-with-no-verbal-feedback versus fading-with-no-feedback, $F(1,25) = 4.83$, $p < 0.025$. Analyses of changes in performance over the five days revealed three significant group differences:

·Snellen letter acuity change superiority for the group receiving fading-with-no-verbal-feedback versus fading-with-no-feedback, $F(1,25) = 5.10$, $p < 0.020$;

·Ortho-Rater checkerboard acuity change superiority for the group receiving fading-and-feedback versus no-treatment, $F(1,25) = 5.92$, $p < 0.010$;

·High-contrast Tumbling E acuity change superiority for the group receiving fading-and-feedback versus no-treatment, $F(1,25) = 5.94$, $p < 0.010$.

Group-specific day-1 and day-5 acuities were compared with correlated t-tests. Only those participants receiving the fading-and-feedback treatment displayed significant changes in Snellen letter acuities, $t(5) = 3.43$, $p<.019$. Three of the five groups displayed significant changes in their high-contrast Tumbling E resolution acuities, some groups showing significant changes from their baseline performances as early as day-3 or day-4:

·Fading and feedback; day-3 $t(5) = 2.77$, $p<.039$, day-4 $t(5) = 4.14$, $p<.009$, day-5 $t(5) = 3.84$, $p<.012$;

·Fading with no verbal feedback; day-5 $t(5) = 3.22$, $p<.023$;

·Fading with no feedback; day-4 $t(5) = 4.24$, $p<.009$, day 5-$t(5) = 4.28$, $p<.008$.

The same three treatment groups performed significantly better at resolving low-contrast Tumbling E's during the course of their five-day participation:

·Fading and feedback; day-4 $t(5) = 4.25$, $p<.009$, day-5 $t(5) = 4.06$, $p<.010$;

·Fading with no verbal feedback; day-4 $t(5) = 2.96$, $p<.031$, day-5 $t(5) = 4.20$, $p<.009$;

·Fading with no feedback; day-4 $t(5) = 2.74$, $p<.040$, day-5 $t(5) = 2.94$, $p<.032$.

No group-specific correlated-t analyses revealed any significant differences in contrast sensitivity, Tumbling E blur tolerance, letter blur tolerance, or pupil size.

Fading and Feedback

Previous research suggested that those trained with fading and feedback would improve significantly more than those receiving no treatment (Collins et al., 1981). To a large degree, that finding was supported in this investigation. The average subject treated with fading and feedback displayed significantly better posttraining Snellen letter acuity and both larger Ortho-Rater acuity and high-contrast Tumbling E resolution changes than the average subject who received no treatment. Fading and feedback participants had higher average fifth-day Snellen letter, high-contrast, and low-contrast Tumbling E resolution acuities than subjects in any other group. They were able to recognize both letters and Tumbling E's that were more blurred and the changes in some of their contrast sensitivities were greater than that of any of their group counterparts. The only acuity measure on which the average fading and feedback member's fifth-day performance was beaten was Ortho-Rater checkerboard resolution on which he took a second

to the average subject trained with fading and no verbal feedback.

Verbal and Nonverbal Feedback

How the treatment of subjects trained with fading and feedback and those trained with fading and no verbal feedback differs seems clear--verbal feedback. There is a need, however, for further consideration of both components of this difference, the verbal and the feedback. Those trained with fading and feedback were verbally told the correct orientations if they misidentified any or all of the Tumbling E's on the screen. Those trained without verbal feedback were not told whether they correctly identified the orientations.

Posttest questionnaires revealed that five of the six participants treated with fading and no verbal feedback did, in fact, discern feedback during the training. Subjects trained with fading and no verbal feedback reported that they knew if they had made an error in identification based on the movement of the screen. If the screen was moved away from them they knew they had made no errors; if it was moved nearer to them the knew they had made an error. In comparison, those trained with fading and no feedback were not told how they did and, in addition, the screen was appreciably advanced and retreated between repositionings, denying observers the opportunity to judge performance based on movement of the screen. The same questionnaires revealed that, as expected, subjects trained with no feedback discerned no feedback regarding their report accuracy. Thus the group trained with fading and no feedback qualifies as a comparison group for those trained with fading and no verbal feedback, allowing assessment of the verbal component of the verbal feedback.

Comparing the fading and no verbal feedback group to both its fading and feedback and fading with no feedback cousins allows one to judge with which group it is most akin. When directional acuity changes (depicted in Table 2) for the fading and no verbal feedback group and the fading with no feedback group are compared, there is only a 53 percent agreement. There is, by contrast, an 80 percent agreement in directional acuity changes between fading and feedback and fading and no verbal feedback group participants. Most striking is the lack of improvements in Snellen acuity made by those receiving no feedback.

There was a statistically significant facilitation difference between final-day Snellen letter acuities and overall Snellen performance changes when the fading and no verbal feedback group performances were compared to the fading with no feedback group performances. Similarly, twice as many subjects discerning feedback as not discerning feedback improved in Ortho-Rater checkerboard acuity. These findings lend statistical support to the supposition made by Collins et al. (1981) that: "A combination of contingent fading plus feedback may be slightly more effective than contingent fading alone." (p. 699). This combinatorial advantage may be realized even if the feedback is only discernible by the observer as opposed to delivered verbally by the examiner.

Fading-Only

Fading, in and of itself, does not appear to be as effective a treatment as does fading and feedback or what might more fairly be considered fading and other than verbal feedback . However, only those groups treated with the fading component showed significant average fifth-day versus first-day

high-contrast Tumbling E resolution improvements. Still needed, though, is an explanation of the Snellen acuity improvement made by the no-treatment group members as opposed to the lack of improvement made by those receiving the fading-only treatment. Subjective experimenter observations supported by a portion of the previously mentioned posttraining questionnaires might help explain some of the improvement or lack thereof.

Motivation

Based on experimenter subjective evaluation, those trained with fading and no feedback seemed less excited about the research as subsequent hours of participation elapsed. Each day there was a treatment period spanning approximately 30 minutes when there was nothing said between the experimenter and the subject other than the experimenter prompt, "Report" followed by an observer-reported, "Up, up, down, left," a three second break followed by, "Report" and once again, "Down, up, left, right," etc. There was a consistent reduction in participant enthusiasm by the 40th or 50th presentation of the day. Receiving no feedback, they did not know how they were doing but the contingent nature of the presentation size required of them continuous effortful observation. Conversely, participants who received no treatment watched distant recorded music videos and were required to make only a few effortful observations. The posttraining questionnaires allowed a more objective comparison of what might be considered a "motivation" factor.

Following their fifth day of participation, each subject answered the question, "If this training were 80 percent guaranteed to improve your vision, how many hours of your free time would you be willing to participate in order

to achieve 20 __acuity" (The blank was filled-in with an acuity equivalent to two Snellen lines better then their starting acuity). The median response for all 30 subjects was 10 hours. Due to the small sample size and variance ranges, statistically significant differences were not found but a trend was evident. The average fading-with-no-feedback participant said he would be willing to participate in 5 hours of training in contrast to the average no-treatment subject's 20 hours. This difference in a desire to continue participation, even with a hypothetically strong probability of acuity improvement, lends support to the supposition that the lack of feedback made the task undesirable. The lack of enthusiasm caused by the absence of feedback might have minimized some of the possible fading treatment component's acuity enhancement. Lack of feedback, however, does not altogether negate acuity enhancement. Six of six subjects treated with fading and no feedback *still displayed improved posttraining* high- and low-contrast Tumbling E resolutions.

Generalization from Treatment to Nontreatment Stimuli

Many of the vision performance measurements in this investigation were highly correlated before, during, and after treatment . Figures B-1 through B-8 graphically display the statistically significant correlations between pretraining Snellen letter acuity and initial Ortho-Rater checkerboard acuity, high-contrast Tumbling E resolution acuity, and low-contrast Tumbling E resolution acuity (see Table B-1) . Ortho-Rater checkerboard acuity was similarly moderately correlated with high- and low-contrast Tumbling E resolution acuities. The correlation between each of these initial Snellen and Ortho-Rater measurements and progressive daily posttraining

measurements remained significant (see Table B-3). Figure B-4 graphically displays the statistically significant correlation between preliminary high- and low-contrast Tumbling E resolution acuities, R(28) = .99, p<.001.

Pretraining total contrast sensitivity was significantly correlated with both preliminary Snellen letter and Ortho-Rater checkerboard acuities (see Table B-1). Each frequency in the overall contrast sensitivity test was likewise correlated with Ortho-Rater acuity; however, the 18.0 cpd frequency resolution was not significantly correlated with Snellen acuity, R(28) = -.41, p<.065. Both high- and low-contrast Tumbling E acuities were correlated with total contrast sensitivity. Each frequency component in the overall contrast sensitivity test was also correlated with both Tumbling E performances. Initial defocused letter recognition was correlated with pretraining Snellen letter acuity but failed to remain correlated as training progressed beyond the first day (see Table B-2). Defocused letter recognition began and remained correlated with defocused Tumbling E resolution.

Fifth-day posttraining Snellen letter, Ortho-Rater checkerboard, and Tumbling E acuities remained highly correlated as shown in Figures B-5, B-6, B-7, and B-8. None of the respective posttraining R values was less than its pretraining counterparts and some increased as much as 5 percent (see Table B-3).

Low-Contrast E Resolution Performance Generalization

The fact that 60 percent of those who improved in Tumbling E acuity also improved in universally nontreated Snellen letter recognition implies generalization of acuity from one task to another, from performance

measured with one technique to performance measured against another standard. Fading and feedback group members displayed significant improvement after only three days of training. Each group treated with fading demonstrated significant high-contrast Tumbling E resolution acuity enhancement.

The generalization of high-contrast Tumbling E training to other acuity tasks is reflected in the daily strong correlations between high- and low-contrast Tumbling E resolution acuities. Each day, trained high-contrast E acuity allowed resolution of smaller and smaller targets. Posttraining and even consistent subsequent-day low-contrast E acuities were commensurately improved. Every subject who displayed a five-day improvement in high-contrast E resolution also showed a low-contrast five-day improvement. More than 70 percent of those trained with high-contrast E's displayed a total contrast sensitivity superior to their pretraining performance. They were able to identify the orientations of gratings of lesser contrast, smaller Snellen letters, and more distant low-contrast E's, all stimuli on which they did not receive training. The training-induced high-contrast E acuity enhancement, however, did not generalize to blur interpretation or influence pupil size.

This high correlation between Snellen letter recognition and Ortho-Rater checkerboard acuity might shadow how critical acuity measurements can be influenced by the specific test. Five of 30 subjects displayed improved fifth-day Snellen letter recognition with no commensurate Ortho-Rater improvement. Conversely, on the fifth-day of testing, examination of Ortho-Rater measurements substantiated improvement for two subjects that were not corroborated by Snellen letter recognition. Comparison of the acuity assessments made with these two instruments on the fifth day of training

revealed that 42 percent of the time they resulted in the same performance score. Snellen-letter assessed acuity was higher than the same subject's Ortho-Rater assessed acuity 39 percent of the time. Ortho-Rater-assessed acuity reflected performance superior to that measured with the Snellen letter standard 19 percent of the time. The more-than-occasional inconsistency between measurements made with the Snellen letter charts and the Ortho-Rater checkerboard display might prove critical to someone with performance near an acuity score cut-off.

One person might be judged to have less acuity than another when, in fact, they have identical acuities as measured with another widely accepted assessment tool. Inspection of posttraining data substantiates the existence of such occurrences. If 20/20 uncorrected acuity was required to enter training to become an umpire, four participants in this study would be assessed as qualified based on their Snellen letter recognition performances. Their Ortho-Rater checkerboard assessed acuities, however, would have left them unqualified with acuity scores of 20/22. These four people's losses would have been one person's gain as that subject's Snellen performance was 20/25 but his Ortho-Rater acuity was 20/20.

This same reversal of decisions based on the type of task might determine the course of an entire career. Waivers to enter military pilot training are fairly routinely granted for uncorrected acuity no worse than 20/70. In this study, fifth-day performance would have resulted in two people being granted waivers based on 20/70 Snellen performances as long as their 20/100 Ortho-Rater performances went undetected. If instead of Snellen chart assessments Ortho-Rater checkerboard tests had been administered, these two subjects would not have been granted waivers to

enter training. Two different subjects from this study, however, would have been grated waivers with 20/67 acuities on the Ortho-Rater but 20/100 Snellen letter acuities. Some people feel that what might settle this discrepancy between measurement techniques is to use a broader standard where contrast sensitivity is measured with various stimuli of known frequencies.

Contrast Sensitivity Generalization

The correlation between fifth-day total contrast sensitivity and both fifth-day Snellen letter and Ortho-Rater checkerboard acuities remained significant (see Table B-3). Each frequency component measured on day-5 in the overall contrast sensitivity test likewise remained correlated with both acuities. Both fifth-day high- and low-contrast Tumbling E acuities were correlated with fifth-day total contrast sensitivity and each of its frequency components. The highest correlations were with 3.0 cpd frequency resolution performance; high-contrast-E $R(28) = -.81$, $p<.001$, low-contrast-E $R(28) = -.83$, $p<.001$. It is this 3.0 cpd frequency that differentiated most of the subjects in this study from the VISTECH "normal range" of performances to be addressed later in Experiment Two. Regardless of the training procedure, there was a significant increase in the total number of gratings identified when day-1 performance was compared with day-5 performance.

Performance Change Generalizations

Changes between the majority of the eight vision tasks were highly correlated (see Tables B-2 and B-4). Some of these change combinations are displayed in Figures B-9 through B-12. Snellen Letter acuity change

was significantly correlated with Ortho-Rater checkerboard acuity change, both Tumbling E acuity changes, and defocused letter recognition change. As depicted in Figure B-12, posttraining high- and low-contrast Tumbling E resolution changes remained highly correlated, $R(28) = .99$, $p<.001$. Ortho-Rater checkerboard acuity changes were likewise correlated with the high- but not the low-contrast Tumbling E acuity changes and in addition correlated with total contrast sensitivity.

Initial-day pretraining performances, fifth-day posttraining performances, and resultant changes in performances were generally highly correlated. These correlations were expected but more surprising were the inconsistencies between the Snellen letter recognition changes and the Ortho-Rater checkerboard acuity correlates. Both acuities were initially highly correlated with each other and high-contrast Tumbling E resolution. Changes in Snellen acuity, however, were also correlated with changes in defocused letter recognition, whereas Ortho-Rater acuity changes were correlated with total contrast sensitivity changes. Evidence that these two measures of acuity might not be measuring the same things is shown in both the directional changes of performances and fifth-day measurements made with both tools.

Estimation of Snellen Letter Acuity Change from Changes in Acuity Mechanisms

A linear regression model was constructed in an attempt to predict the change in Snellen letter acuity from a subject's initial Snellen acuity and training-induced changes in both pupil size and recognition of blurry stimuli:

$$\Delta\text{Snellen Letter Acuity} = (f)\text{Initial Acuity} + \Delta\text{Pupil Size} + \Delta\text{Blur Interpretation}.$$

Each subject's logarithmically transformed pretraining Snellen letter acuity, pupil size, defocused Tumbling E resolution change, and defocused letter recognition change was entered into a regression equation. Pupil size failed to significantly contribute to the analysis of variance and was eliminated as a predictor. Both Tumbling E and letter blur recognition changes and the transformed preliminary Snellen acuity did result in an equation that significantly accounted for the variance in Snellen letter acuity change, $\underline{F}(3,26) = 10.73$, $\underline{R}^2 = .56$, $\underline{p}<.001$:

$$\Delta\text{Snellen Letter Acuity} = -.17 + .34\ X - .36\ Y + .61\ Z$$

where

X = Log Initial Snellen Acuity

Y = Change in Tumbling E Blur Recognition

Z = Change in Letter Blur Recognition

If any of the three independent variables in the equation was dropped from the model, the variance accounted for was significantly decreased. All 30 subjects' performances were entered into this equation and their resultant residual scores are plotted in Figure 6.

The residuals in Figure 6 are generally small and case-by-case analysis reveals that nearly 75 percent of the time the equation's predicted posttraining Snellen acuities fell within one chart line of the actual fifth-day performance. Only one of six subjects in each treatment group displayed a Snellen acuity more than one chart line graduation away from that predicted.

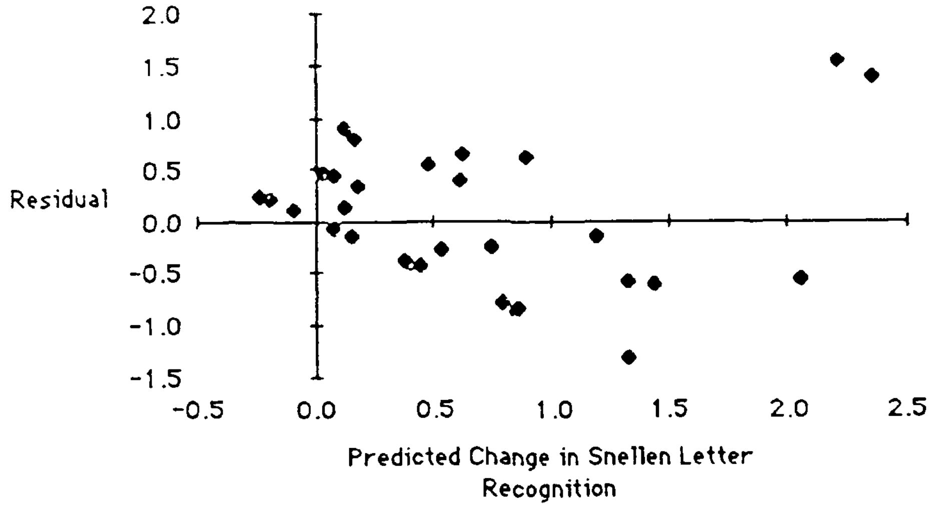

Figure 6. Predicted changes in Snellen letter acuity residuals.

The worst forecasting of Snellen letter performance changes was realized when scores were predicted for those receiving no treatment.

A second equation was constructed incorporating all three of the significant predictor variables from the previous equation and dummy variables accounting for the type of training: fading and feedback, fading and no verbal feedback, fading and no feedback, feedback only, and no treatment. Stepwise regression produced a model with the same predictor variables as the previous equation with the inclusion of the third type of training , fading and no feedback. The fading-and-no-feedback training dummy variable was the second entered into the equation, $F(4,25) = 11.99$, $R^2 = .66$, $p<.001$:

$$\Delta \text{Snellen Letter Acuity} = -.02 + 1.66\ X - .30\ Y + .57\ Z - .78\ W$$

where

X = Log Initial Snellen Acuity

Y = Change in Tumbling E Blur Recognition

Z = Change in Letter Blur Recognition

W = Fading and no feedback training

Only fading-and-no-feedback group membership contributed significantly to the prediction of change in participant Snellen Letter recognition acuity. The weighting associated with the single type of training indicates that resultant changes in Snellen letter acuities for individuals receiving fading-and-no-feedback training are negatively influenced. There appears to be something about the lack of feedback that negatively influences operant training facilitation of Snellen letter acuity.

Endurance of Training-Facilitated Acuity Enhancement

Six subjects were retested between 27 and 45 days after their fifth training sessions. Only one regressed in Snellen letter acuity back to his day-1 performance (Day-1, 20/70, Day-5, 20/50, 45-days-later, 20/70). The remaining five maintained their fifth-day performances over the weeks with neither further training nor practice. No subject regressed in Ortho-Rater checkerboard acuity but two improved further from their fifth-day performances (Subject 1: Day-1, 2.0, Day-5, 2.0, 45-days-later, 1.43; Subject 2: Day-1, 1.43, Day-5, 1.25, 27-days-later, 1.11). There was no regression in high-contrast Tumbling E resolution acuities but two regressed

in their low-contrast E acuities; one regressed 13 cm compared with his 165 cm 5-day gain and another regressed 1 cm compared with his 61 cm 5-day gain. Only one subject's total contrast sensitivity regressed but he still displayed superior performance compared to his first day of participation. One person's total contrast sensitivity remained unchanged and the remaining four improved in both their total performances and some specific frequencies.

The persistence of these training-induced performance gains lends support to the belief that the treatment is more than a mere training artifact. It is more likely that subjects learned something about their performance technique or specific attributes of the stimuli that was enduring enough to allow its recall and application weeks after training.

Comparison Group to Assess Training Performance Enhancement

The need for a valid experimental design dictated that the subjects in the control condition of this investigation be treated as much like those subjects receiving treatment as possible with the exclusion of the treatment. This required that the subjects receiving no treatment attend the same number of training sessions, over the same time frame, and be measured in the same ways as their treatment counterparts; the no-treatment subjects merely watched a distant television presentation in lieu of receiving any treatment. Although this established a group allowing legitimate scientific comparison, it did not satisfy those who would like to know how much the treatments would help compared to nothing, or "no-participation".

The analysis was accomplished again with the addition of a control group whose performance was measured on day-1 and day-5 with no

interim contact. The mean pretraining and fifth-day posttraining performances by group assignment are repeated in Table 3 with the addition of the control group performances. Table 4 presents a summary of the day-5 versus day-1 directional changes by group members on each of the eight performance tests. The posttraining standardized score performance changes with the addition of the control group are shown in Figure 7. Of most interest was the orthogonal contrast comparing those who participated in five 1-hour sessions (treatment and no-treatment group participants) to those minimally contacted (control group participants).

Analysis of group-specific subject scores resulted in no appreciable changes from the previously reported results with regard to Snellen letter acuity, contrast sensitivity, blur interpretation, or pupil size. However, analyses did reveal the following main effects:

- Ortho-Rater checkerboard acuity change, $\underline{F}(5,30) = 2.48$, $\underline{p}<.05$;
- High-contrast Tumbling E resolution acuity change, $\underline{F}(5,30) = 2.93$, $\underline{p}<.02$;
- Low-contrast Tumbling E resolution acuity change, $\underline{F}(5,30) = 2.43$, $\underline{p}<.05$.

When the control group performances were compared to those of the other 30 participants, the subjects who received no treatment became a group that comparatively did receive treatment; their regimen was more similar to those being treated. The significant main effects lend statistical evidence to the superiority of improvement made by those participating in consecutive-day sessions, even without treatment but having a regimen similar to that of a treatment subject. The acuity standardized score

Table 3

Mean Pretraining and 5th-Day Posttraining Performance by Training Type with Control

Group	Snellen Acuity Pre	Snellen Acuity Post	Ortho-Rater Acuity Pre	Ortho-Rater Acuity Post	High Contrast E Acuity Pre	High Contrast E Acuity Post
Fading & Feedback	20/52	20/29	20/42	20/30	20/32	20/25
Fading (No Verbal Fdbk)	20/52	20/32	20/44	20/35	20/32	20/25
Fading (No Feedback)	20/52	20/53	20/43	20/40	20/38	20/34
Feedback (No Fading)	20/52	20/40	20/45	20/40	20/37	20/33
No Treatment	20/52	20/39	20/47	20/45	20/34	20/32
Control (Day 1 & Day 5)	20/52	20/53	20/43	20/49	20/36	20/36

Group	Low Contrast E Acuity Pre	Low Contrast E Acuity Post	Contrast Sensitivity Pre	Contrast Sensitivity Post	Defocused E Acuity (D) Pre	Defocused E Acuity (D) Post
Fading & Feedback	20/34	20/28	22.0	23.8	0.74	0.75
Fading (No Verbal Fdbk)	20/35	20/30	17.7	20.2	0.75	0.72
Fading (No Feedback)	20/39	20/35	17.0	20.3	0.70	0.70
Feedback (No Fading)	20/38	20/33	18.7	20.7	0.74	0.72
No Treatment	20/34	20/33	18.8	20.0	0.71	0.74
Control (Day 1 & Day 5)	20/38	20/38	18.7	18.7	0.73	0.72

Group	Defocused Ltr Acuity (D) Pre	Defocused Ltr Acuity (D) Post	Pupil Size (mm) Pre	Pupil Size (mm) Post
Fading & Feedback	0.73	0.78	2.80	2.73
Fading (No Verbal Fdbk)	0.77	0.77	2.70	2.55
Fading (No Feedback)	0.75	0.77	2.70	2.72
Feedback (No Fading)	0.75	0.75	2.60	2.62
No Treatment	0.71	0.76	2.65	2.65
Control (Day 1 & Day 5)	0.74	0.74	2.67	2.67

changes presented in Figure 7 strikingly display the comparatively dismal improvement made by control subjects. Their day-1 versus day-5 scores were very consistent but their near total lack of average improvement is all

Table 4

Directional Changes Between Pretraining and 5th-Day Posttraining Performance by Training Type with Control

Group	Snellen Acuity	Ortho-Rater Acuity	High Cont. E Acuity	Low Cont. E Acuity	Contrast Sensitivity	E Blur Tolerance	Letter Blur Tolerance	Pupil Size
Fading & Feedback	6 Better - -	5 Better 1 Same -	6 Better - -	6 Better - -	4 Better - 2 Worse	4 Better - 2 Worse	5 Better - 1 Worse	2 Bigger 2 Same 2 Smaller
Fading (No Verbal Fdbk)	5 Better 1 Same -	4 Better 1 Same 1 Worse	5 Better - 1 Worse	5 Better - 1 Worse	4 Better 2 Same -	2 Better 1 Same 3 Worse	3 Better - 3 Worse	2 Bigger - 4 Smaller
Fading (No Feedback)	- 6 Same -	2 Better 4 Same -	6 Better - -	6 Better - -	6 Better - -	4 Better - 2 Worse	4 Better - 2 Worse	2 Bigger 2 Same 2 Smaller
Feedback (No Fading)	3 Better 3 Same -	3 Better 2 Same 1 Worse	6 Better - -	6 Better - -	3 Better 1 Same 2 Worse	2 Better 1 Same 3 Worse	3 Better 1 Same 2 Worse	1 Bigger 3 Same 2 Smaller
No Treatment	4 Better 2 Same -	1 Better 5 Same -	3 Better 1 Same 2 Worse	4 Better 1 Same 1 Worse	4 Better 1 Same 1 Worse	2 Better 1 Same 3 Worse	6 Better - -	1 Bigger 3 Same 2 Smaller
Control (Day 1 & Day 5)	1 Better 4 Same 1 Worse	- 4 Same 2 Worse	2 Better 1 Same 3 Worse	3 Better 1 Same 2 Worse	1 Better 3 Same 2 Worse	4 Better - 2 Worse	4 Better - 2 Worse	2 Bigger 1 Same 3 Smaller

but universally exceeded by any treatment group on any performance measurement.

The contrasts comparing treatment groups to the control group on three performance measurements were all significant:

- Treatment versus control group Ortho-Rater $F(1,30) = 8.15$, $p<.007$;
- Treatment versus control group High-contrast-E $F(1,30) = 10.83$, $p<.002$;
- Treatment versus control group Low-contrast-E $F(1,30) = 10.46$, $p<.003$.

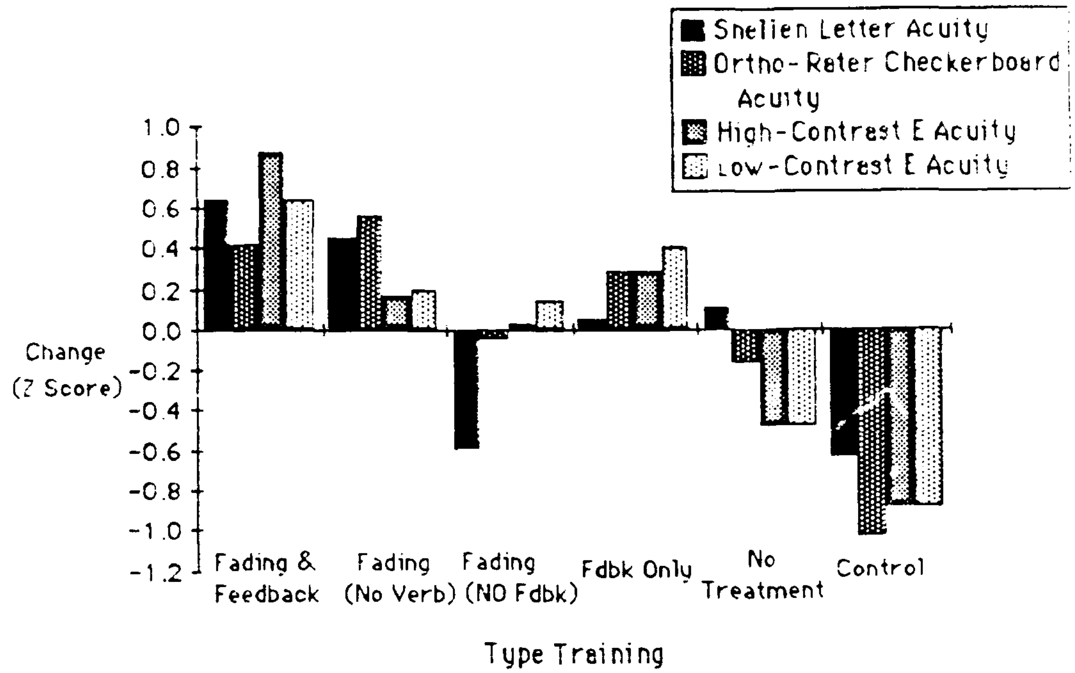

Figure 7. Acuity changes by training type with control group.

There was something about five-session participation that made subjects receiving no treatment improve more than their control counterparts who, likewise, received no training but, in contrast, were not measured or motivated each day. Relaxation or familiarity with the test procedures and environment may have accounted for some of the performance facilitation displayed by consecutive-day participants. A counter example, however, can be found in the fact that none of those trained with feedback only displayed any Snellen letter acuity enhancement.

If a person was trying to sell his services as a visual acuity therapist, he would likely publish comparative data that pits the performance of those who have received treatment against those who did not receive any treatment; those referred to as "controls" in this investigation. With such an applied

perspective, it seems inappropriate to compare treated subjects to those who came to treatment sessions each day and were measured in the same way as treatment participants, but who then sat passively in lieu of receiving treatment to be assessed once more before departing. To the applied therapist, the control-group subjects appear to be a more natural, realistic, and appropriate comparison group.

Summary

High-contrast Tumbling E resolution training with combinations of fading and feedback facilitated improvements in high- and low-contrast Tumbling E resolutions, Ortho-Rater checkerboard resolution, Snellen letter recognition, and contrast sensitivity performances. Participants receiving fading-and-feedback training had the highest average posttraining Snellen letter, high-contrast, and low-contrast Tumbling E resolution acuities, and letter blur tolerances. Changes in acuity were predictable from the linear combination of changes in defocused letter and Tumbling E recognition scores and logarithmically transformed initial Snellen letter recognitions. The universal lack of regression in six subjects' retested high-contrast Tumbling E resolution and Ortho-Rater checkerboard acuities confirmed the relative endurance of training-induced enhancements.

EXPERIMENT TWO

Method

The second experiment was used to examine whether training to recognize blurry letters, pupillary control, or accommodative flexibility subsequently resulted in Snellen letter recognition acuity improvement. The goal of this experiment was to do the following:

- Determine if pupillary control, accommodative flexibility, or blur interpretation training influences their respective acuity mechanisms.
- Ascertain how much average acuity improvement each of these training techniques produces.
- Determine if there are significant differences in improvement between the techniques.
- Ascertain the degree to which Snellen letter acuity can be predicted from other task measurements, especially VISTECH contrast sensitivity.

Subjects / Design

Twenty-six myopic U.S. Air Force Academy freshmen and sophomores (ages 19-23) were divided into six groups; four groups of five participants and two groups of three participants. One group of five was trained in pupillary control while their control counterpart five-member group was treated the same excluding training. A third group of five received accommodative flexibility training and another group treated identically excluding training. Finally, a group of three received blur-training and the remaining group of three was treated identically excluding blur-training. The

pupillary-control and accommodative-control treatment groups were composed of subjects with acuities of 20/25, 20/40, 20/50, 20/70, and 20/100. The blur-interpretation treatment group was composed of subjects with acuities of 20/25, 20/40, and 20/70. The participants in the control groups had initial acuities identical to their training group counterparts. As in experiment one, participation was voluntary and only glasses and soft contact lens wearers served as subjects.

Apparatus

Apparati were identical to those used in Experiment One with the following exceptions:

Pupil Diameter

During biofeedback pupillary-control training, the Whittaker Corporation Series 800 T.V. Pupillometer output was amplified by a sweep function generator and presented as an auditory tone to the participant. The tone ranged from approximately 100 to 1000 Hz commensurate with pupil size.

Accommodative Control

Computer-displayed Snellen letters served as stimuii for this training. The computer's movable platform allowed it to be slid along a 610 cm (20 ft) rail while subjects attempted to keep the stimuli in focus.

Procedures

Each subject participated in a daily 1-hour session for five consecutive days. No subjects were allowed to squint while their acuity was being

assessed or training was being accomplished. During the first 15 minutes of each session the participant, without corrective lenses, watched a distant television. No near visual focusing was allowed during this accommodative relaxation period.

After the relaxation period, each subject's Snellen acuity was assessed. Participants read the chart from top to bottom (20/200 to 20/10) at a distance of 6.1 m (20 ft) until they correctly identified less than 100 percent of the letters on a given line. Both high- and low-contrast Tumbling E resclution distance thresholds were then ascertained. On the first day of participation, subjects identified the locations of Ortho-Rater checkerboard presentations and each subject's contrast sensitivity was assessed. The Snellen letter and Tumbling E measurements were repeated at the beginning of each day for treatment and nontreatment group members.

Each subject's group-dependent acuity mechanism was then measured. Pupil size treatment and control group subjects viewed a Snellen chart presented at their dark focus for 1 minute while average pupil diameter was ascertained. Accommodative control treatment and control group members viewed computer-displayed Snellen letters at a distance 5 cm closer than their 100-percent recognition threshold. The letters were then slid farther away at approximately 1 cm per second until the subject reported he could no longer recognize all of the fading letters. This accommodative range was measured four times for each of these group members. Blur interpretation treatment and control group members attempted to report the orientation of 10 individually presented Tumbling E's and 10 letter stimuli with the highest tolerable defocus.

After 30 minutes of training for treatment group members or no training for control group members their respective acuity mechanisms and both Snellen letter and Tumbling E acuities were measured in the same manner as they were at the beginning of the session. On the last day of participation, regardless of group assignment, the five initial measurements made on the first day were repeated prior to termination of the session: Snellen letter, Tumbling E resolution, Ortho-Rater acuities, and contrast sensitivity.

Pupillary Control

Pupillary-control treatment and control group subjects read material of their choice (black print on a white background) presented at their dark focus. Those receiving treatment were simultaneously given auditory biofeedback regarding the size of their left pupil. They were instructed to try and make the tone as low as possible (and their pupil size commensurately small). Subjects receiving no treatment had no knowledge of their pupil size.

Accommodative Flexibility

Subjects receiving the accommodative-control treatment repeatedlv attempted to keep high-contrast Snellen letters in focus while [illegible] ere moved farther away. They attempted this accommodative flexibility as many as 30 times per training session. Their nontreatment counterparts received no practice at accommodative flexibility. They reported the orientations of Tumbling E's presented at their pretest resolution threshold.

Blur Interpretation

These treatment group members attempted to resolve as many as 40 high-contrast Tumbling E's with the maximum tolerable defocus. They were given feedback regarding their accuracy. The blur interpretation control group subjects reported the orientations of approximately the same number of E's defocused 1/4 D less than their pretest tolerance.

Results and Discussion

Pupillary Control Training

Table 5 shows the pre- and posttraining performance averages for the groups receiving and not receiving pupillary biofeedback training. Initially, there was no difference between Snellen letter acuity group averages. Neither were there any significant differences between the other five performance measurements including pupil size. Figure 8 is a plot of the changes in pupil size over the five days of training for each group. Although the group receiving no pupil size biofeedback started with an average smaller pupil than their feedback counterpart, on the fourth-day the acuity advantage of a smaller pupil reversed groups. The average subject receiving pupil size biofeedback had a smaller pupil on day-5 than his average untrained complement, $t(8) = 3.593$, $p<.008$.

Of the five remaining performance measurements, the group receiving biofeedback showed more average improvement than its no feedback counterpart on both Snellen letter acuity and Ortho-Rater checkerboard acuity. All five of the subjects receiving feedback displayed some improvement in their Snellen letter acuities (see Table A-2). Likewise, three

Table 5

Pupil Control Training Mean Pretraining and 5th-Day Posttraining Performance by Training Type with Performance Ranges

Group	Snellen Acuity Pre	Snellen Acuity Post	Ortho-Rater Acuity Pre	Ortho-Rater Acuity Post	High Contrast E Acuity Pre	High Contrast E Acuity Post
Pupil Training	20/57	20/38	20/40	20/31	20/35	20/30
(Ranges)	(/100-/25)	(/70-/15)	(/50-/18)	(/40-/18)	(/46-/22)	(/45-/20)
No Pupil Training	20/57	20/42	20/42	20/37	20/37	20/32
(Ranges)	(/100-/25)	(/70-/20)	(/67-/18)	(/67-/18)	(/44-/25)	(/44-/25)

Group	Low Contrast E Acuity Pre	Low Contrast E Acuity Post	Contrast Sensitivity Pre	Contrast Sensitivity Post	Pupil Size (mm) Pre	Pupil Size (mm) Post
Pupil Training	20/35	20/31	19.8	20.2	2.48	2.14
(Ranges)	(/46-/20)	(/45-/21)	(10-32)	(14-33)	(3.2-2.0)	(2.4-2.0)
No Pupil Training	20/36	20/32	18.8	20.6	2.40	2.58
(Ranges)	(/45-/29)	(/44-/26)	(11-27)	(14-29)	(2.9-1.8)	(2.9-2.4)

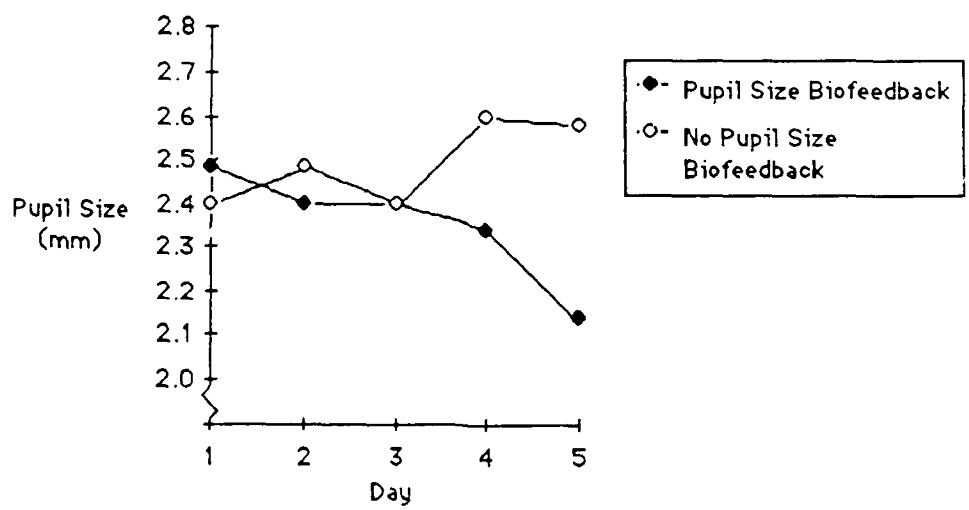

Figure 8. Daily average pupil sizes by training type.

of the five subjects receiving no pupil size feedback displayed some Snellen letter acuity improvements. A statistically significant change was found when biofeedback subjects' day-1 Snellen acuities were compared to their day-5 acuities, $t(4) = 5.73$, $p<.006$. The Ortho-Rater acuity improvements were not statistically significant.

Accommodative Flexibility Training

Pre- and posttraining performance averages for the groups receiving and not receiving accommodative range training are shown in Table 6. Initially, there was no difference between the groups' Snellen letter acuities and no significant difference between any of the other five performance measurements. Figure 9 is a plot of the average accommodative ranges over the five days of training for both groups. Each subject's accommodative range remained relatively constant in breadth but its beginning and ending points increased from the previous day's performance, 88 percent of the time for those receiving range training and 80 percent of the time for those receiving no range training. The initial average accommodative range for those receiving training reflected a greater beginning, breadth, and ending range of accommodative flexibility. On the fifth day their average performance reflected even more range superiority in its beginning, breadth, and ending over the group receiving no range training. None of these differences, however, was statistically significant, lessening the viability of this training as a means to achieve acuity enhancement.

Each day the beginning point of a subject's accommodative range was highly correlated with his Snellen letter acuity, $R(8) = -.840$, $p<.003$. Snellen acuity for participants receiving accommodative range training on days four

Table 6

Accommodative Flexibility Training Mean Pretraining and 5th-Day Posttraining Performance by Training Type with Performance Ranges

Group	Snellen Acuity Pre	Snellen Acuity Post	Ortho-Rater Acuity Pre	Ortho-Rater Acuity Post	High Contrast E Acuity Pre	High Contrast E Acuity Post
Accom. Range Training	20/55	20/27	20/34	20/28	20/31	20/27
(Ranges)	(/100-/25)	(/40-/15)	(/50-/18)	(/33-/20)	(/47-/20)	(/37-/20)
No Accom. Range Training	20/55	20/34	20/35	20/33	20/35	20/32
(Ranges)	(/100-/25)	(/50-/15)	(/50-/22)	(/50-/20)	(/47-/25)	(/44-/20)

Group	Low Contrast E Acuity Pre	Low Contrast E Acuity Post	Contrast Sensitivity Pre	Contrast Sensitivity Post	Accommodative Range Pre	Accommodative Range Post
Accom. Range Training	20/32	20/28	20.8	24.2	20/31-30	20/29-28
(Ranges)	(/48-/20)	(/37-/20)	(12-32)	(17-33)	(/40-/20)	(/39-/20)
No Accom. Range Training	20/35	20/34	19.0	21.4	20/34-32	20/33-32
(Ranges)	(/47-/25)	(/44-/21)	(11-29)	(16-34)	(/40-/23)	(/38-/20)

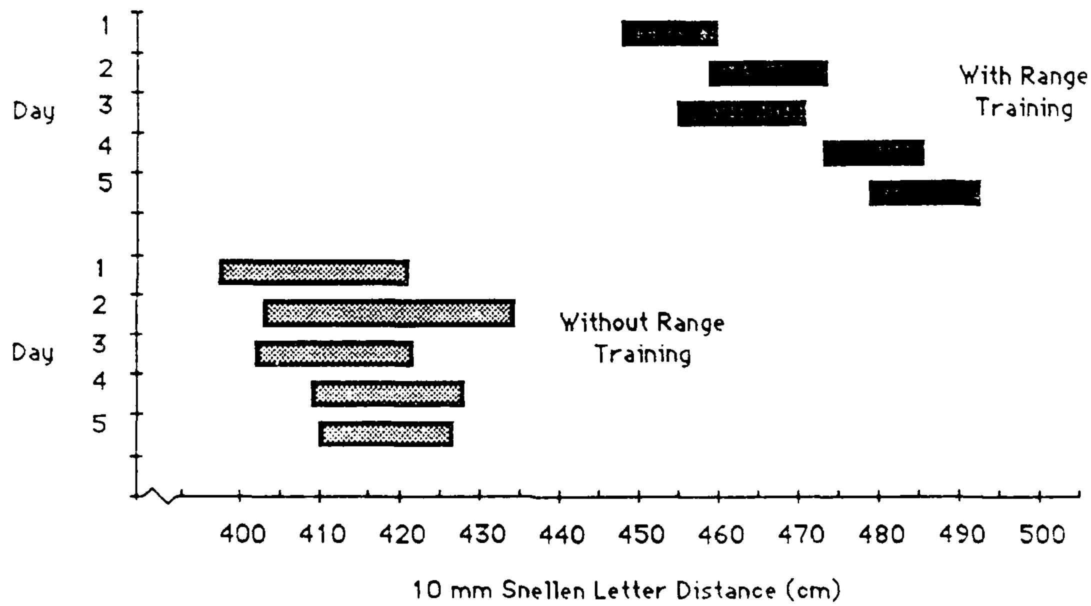

Figure 9. Daily average accommodation range by training type.

and five was superior to their initial performances, day-4 $t(4) = 3.14$, $p<.035$ and day-5 $t(4) = 3.06$, $p<.038$. Everyone who participated in the five-day accommodative range study displayed improved Snellen letter acuity regardless of whether they received training (see Table A-2).

The average fifth-day Ortho-Rater checkerboard acuity, high- and low-contrast Tumbling E resolutions, and total contrast sensitivity for those receiving range training are all higher than their nontrained complement. None of the differences, however, proved statistically significant. The fifth-day total contrast sensitivity of those receiving range training was significantly better than pretraining performance, $t(4) = 5.01$, $p<.009$. Component analysis of the total revealed statistically significant changes in performance for the two highest frequency resolutions, 12.0-cpd $t(4) = 4.00$, $p<.018$ and 18.0-cpd $t(4) = 4.00$, $p<.018$. Four of the five subjects receiving accommodative range training resolved at least one more 12.0 and one more 18.0 cpd grating on their fifth day than they did on their first day. Pretraining contrast sensitivity might prove to be a useful screening tool in selecting subjects who could profit most from accommodative flexibility training. If a subject knew that his acuity was to be measured with grating-type targets, he might profit from accommodative flexibility training, especially in his high-frequency resolution.

Blur Interpretation Training

Table 7 shows the pre- and posttraining performance averages for the groups receiving and not receiving blur interpretation training. There was no initial difference between the groups' Snellen letter acuities and no

Table 7

Blur Interpretation Training Mean Pretraining and 5th-Day Posttraining Performance by Training Type with Performance Ranges

Group	Snellen Acuity Pre	Snellen Acuity Post	Ortho-Rater Acuity Pre	Ortho-Rater Acuity Post	High Contrast E Acuity Pre	High Contrast E Acuity Post
Blur Training	20/45	20/32	20/32	20/32	20/31	20/28
(Ranges)	(/70-/25)	(/50-/20)	(/50-/22)	(/50-/20)	(/46-/22)	(/41-/20)
No Blur Training	20/45	20/50	20/40	20/39	20/32	20/30
(Ranges)	(/70-/25)	(/70-/30)	(/67-/18)	(/67-/18)	(/48-/21)	(/43-/20)

Group	Low Contrast E Acuity Pre	Low Contrast E Acuity Post	Contrast Sensitivity Pre	Contrast Sensitivity Post	Blur Tolerance (D) Pre Tumb E/Ltr	Blur Tolerance (D) Post Tumb E/Ltr
Blur Training	20/33	20/29	20.7	26.0	0.71/0.75	0.79/0.79
(Ranges)	(/47-/24)	(/43-/20)	(12-26)	(18-33)	(.69-.73/.74-.76)	(.77-.81/.79-.79)
No Blur Training	20/34	20/32	23.0	23.7	0.65/0.66	0.71/0.74
(Ranges)	(/50-/20)	(/45-/21)	(14-29)	(15-28)	(.65-.65/.65-.67)	(.70-.72/.79-.79)

significant differences between any of the other five performance measurements. Blur interpretation performance universally improved for both those trained and untrained subjects. There was no significant difference between the posttraining blur tolerances of blur-trained or untrained subjects. All the subjects trained in blur interpretation displayed imprcvements in their Snellen letter acuities. None of those untrained in blur interpretation, however, displayed any Snellen letter acuity enhancement. Figure 10 graphically depicts the changes in defocused Tumbling E and letter recognition over the five days of training for each

group.

The group receiving blur training showed more average improvement than its nontrained complement on four of the remaining five performance measurements. Subjects who received blur training displayed better day-5 performance in Snellen letter acuity, Ortho-Rater checkerboard acuity, high- and low-contrast Tumbling E acuities, and total contrast sensitivity. All three subjects receiving blur training displayed day-1 versus day-5 improvements in Snellen acuity. None of the three subjects receiving no blur training displayed any Snellen acuity improvement; in fact, two performed worse on day-5 than they did on day-1 (see Table A-2). There was a significant difference between the two groups' average changes in Snellen letter acuity, $t(4) = 3.48$, $p<.027$.

The large change between the first- and fifth-day total contrast sensitivity displayed by the group receiving blur training is primarily attributable to its improvement in 6.0 cpd resolution, $t(2) = 3.50$, $p<.079$. On the fifth day, blur

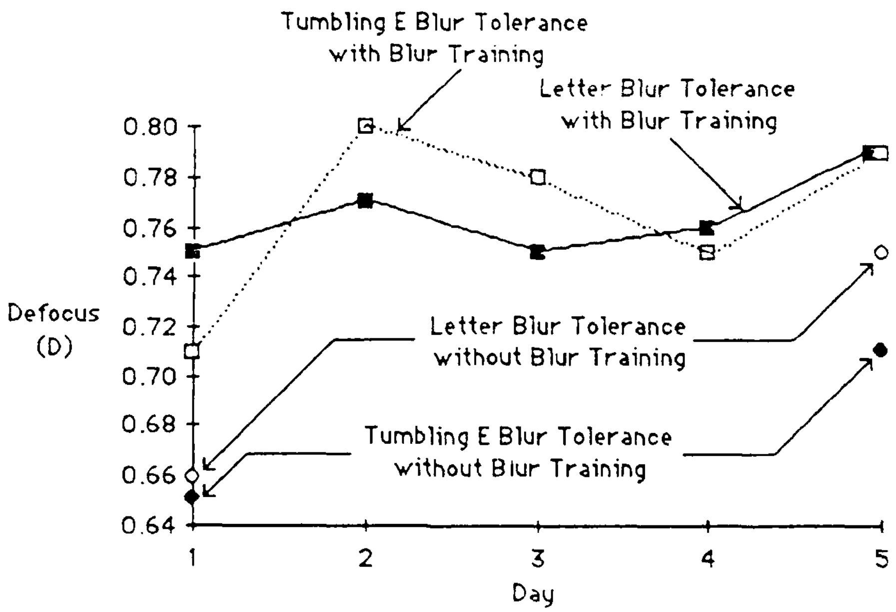

Figure 10. Daily average letter and Tumbling E blur tolerance by training type.

training subjects resolved between one and three more 6.0 cpd gratings than they did during their initial testing. Those trained in blur interpretation resolved between one and three more posttraining 6.0 cpd gratings than in pretraining compared to a maximum change of only one by a single untrained subject.

Differential Effects of Acuity Training

There were no significant differences between pre- or posttraining performance on any of the vision performance tasks except contrast sensitivity. A statistically significant change in 6.0 cpd performance and nearly significant changes in 18.0 cpd and total contrast sensitivity warranted post hoc group comparisons:

- 6.0-cpd-change $F(2,10) = 4.22$, $p<.047$;
- 18.0-cpd-change $F(2,10) = 3.55$, $p<.067$;
- Total-contrast-sensitivity-change $F(2,10) = 3.94$, $p<.054$.

Less conservative than these analyses, a priori planned orthogonal contrasts revealed more contrast sensitivity improvement was made by subjects receiving either accommodative range training or blur interpretation training than by subjects receiving pupil biofeedback training:

- 6.0-cpd-change $F(1,10) = 5.46$, $p<.040$;
- 18.0-cpd-change $F(1,10) = 6.11$, $p<.032$;
- Total-contrast-sensitivity-change $F(1,10) = 7.48$, $p<.021$.

Compared to their pupil training counterparts, the average range training subjects both started with higher first-day performances on these three tasks

and showed more improvements on the fifth day.

Two of these training regimens required effortful interpretation of blurry or distant targets whereas one did not. It may be the recognition component of the accommodative flexibility and blur interpretation training that facilitates grating resolution. Subjects receiving either of these treatments were required to make periodic reports of their ability to resolve a target. They similarly had to resolve and report gratings when their contrast sensitivity was assessed. Pupil biofeedback subjects were not required to periodically resolve targets during their training, only to read while attempting to make their pupil as small as possible. Consequently, they did not get as much practice at resolving, recognizing, or interpreting what they saw.

Equivalence of Snellen Letter Acuity and Other Task Measurements

The initial performance measurements of all 62 subjects in Experiments One and two were used to generate a regression equation to predict pretraining Snellen letter acuity from the other seven task measurements. High-contrast and low-contrast Tumbling E acuity performances tie as the most predictive measurements of Snellen letter recognition acuity; high-contrast-E $F(1,60)=89.46$, $p<.001$ and low-contrast-E $F(1,60)=86.10$, $p<.001$. Ortho-Rater checkerboard acuity is certainly a legitimate predictor of Snellen letter acuity but not as good as either singular Tumbling E resolution performance, $F(1,60)=50.35$, $p<.001$. Adding either Tumbling E performance measurement to the Ortho-Rater acuity predictive equation significantly increases the explained variance: Ortho-Rater and high-contrast-E $F(12,59)=43.89$, $p<.001$; Ortho-Rater and low-contrast-E

$F(2,59)=45.46$, $p<.001$. Neither Tumbling E acuity adds significantly to the predictiveness of the other in a dual variable regression equation.

The ability to predict pretraining Snellen letter acuity was attempted using initial contrast sensitivity measurements. Any of the single-frequency measurements made with the VISTECH charts serve as significant predictors of Snellen acuity:

·1.5-cpd $F(1,60)=32.39$, $p<.001$; ·3.0-cpd $F(1,60)=55.73$, $p<.001$;
·6.0-cpd $F(1,60)=33.68$, $p<.001$; ·12.0-cpd $F(1,60)=13.55$, $p<.001$;
·18.0-cpd $F(1,60)=18.55$, $p<.001$.

Only the dual combination of 3.0 cpd and 6.0 cpd adds significantly to the explanation of variance, $F(2,59)=29.69$, $p<.001$. No addition of other frequency-specific performances contributes significantly to the tandem predictors.

Figure 11 shows the pretraining average number of frequency-specific gratings correctly resolved by participants with each pretraining matched Snellen letter acuity. There are no significant differences between the acuity performances. In fact, the functions are nearly superposed and even cross when comparing 20/30 and 20/40 acuities as well as the upper frequencies for 20/50 and 20/70 acuities. Despite the occasional overlapping functions, the average performance for participants with the worst pretraining Snellen acuity, 20/100, is always lowest and the average performance for the best pretraining Snellen acuity, 20/25, is always the best. The overlap of the performances as shown in Figure 11, however, graphically depicts some of the inaccuracies that can result when one performance measure is used to predict the other.

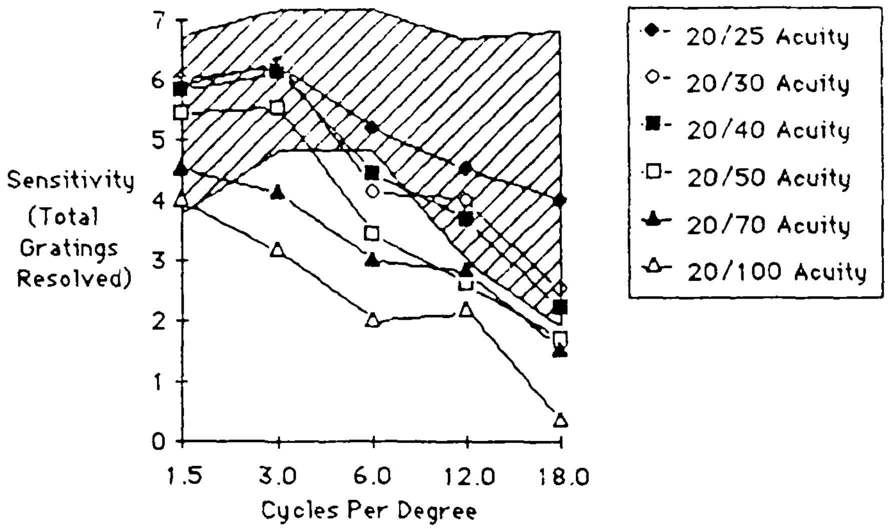

Figure 11. Average number of VISTECH gratings resolved by pretrained Snellen letter acuity with the "normal range" cross-hatched.

VISTECH supplies a Form 984 with the VCTS 6500 distant contrast sensitivity testing kit on which the "normal range" of contrast sensitivities for a person with 20/20 acuity is *shaded*. *Figure* 11 displays this normal range cross-hatched over the pretraining average number of frequency-specific gratings correctly resolved by each of the six acuity-level groupings. Another chart included with the VCTS 6500 depicts "equivalent acuity values" for 6.0, 12.0, and 18.0 cpd resolution performances. In six cases, the frequency-specific performances are depicted as ranges and in two cases as single points. According to VISTECH, a person with 20/25 acuity should identify only the relatively high-contrast 18.0 cpd gratings (numbers 1, 2, and 3 in the series of 9 gratings). Based again on the VISTECH Form 984, a person with 20/100 acuity should identify only the highest contrast 6.0 cpd grating (number 1 in the series of 9 gratings). Figures C-1 through C-6 show these Snellen acuity-specific VISTECH ranges and the pretraining scores for 62 subjects with the respective pretraining Snellen letter acuities.

If the shaded area of "normal range" contrast sensitivity grating performances depicted in the VISTECH literature and in Figure 11 was used to assess initial subject acuities in this investigation, 13 of 62 would have been judged "normal", possessing sensitivity equal to that of a person with normal (20/20) visual acuity. Through the use of pretraining Snellen letter recognition scores, eight of the VISTECH-normal subjects were assessed as 20/25, two as 20/30, two as 20/40, and one as 20/100 (posttraining 20/25). Only two subjects' first-day performances at 1.5 cpd were low enough that they fell outside of the "normal" range. Conversely, one subject with 20/50 Snellen letter acuity resolved <u>more</u> 1.5 cpd gratings than "normal".

The frequency that differentiated most of these subjects from "normal" was 6.0 cpd. Only 22 percent of the subjects had "normal" 6.0 cpd performance. Snellen letter recognition performances allowed assessment of eight as 20/25, two as 20/30, two as 20/40, and two as 20/100 (posttraining 20/40 and 20/25). Posttraining comparisons revealed that only 1 of 13 subjects who improved to a 20/20 or better Snellen letter recognition acuity had contrast sensitivity performance that fell outside of the shaded area; one person with day-5 Snellen letter acuity had grating resolution performance that fell short of the 6.0 cpd "normal" range.

In one sense, the VISTECH "ranges" seem too liberal and in another too conservative. Figure 11 reflects VISTECH's liberal grating resolution "normal range" estimation. Many of those subjects with less than "normal" Snellen letter pretraining acuities of 20/25, 20/30, 20/40, and 20/50 had 1.5 through 18.0 cpd grating performances that fell within the cross-hatched "normal" range. Pretraining contrast sensitivity performance was normal for more than 25 percent of the subjects when their pretraining Snellen letter

acuities were less than "normal": 20/25, 20/30, 20/40, or 20/70. Conversely, the VISTECH "equivalent acuity values" appear to be too conservative. Figures C-1 through C-6 depict contrast sensitivity performances by pretraining Snellen letter acuities that are universally higher than proposed by VISTECH. For example, the average subject with a 20/70 pretraining Snellen letter acuity resolved two 18.0 cpd gratings, good enough to qualify with a VISTECH "equivalent acuity" of 20/30. The VISTECH guidelines suggest that a subject who resolves three 12.0 cpd gratings should have an equivalent Snellen letter acuity of 20/40 or better. In fact, more than 40 percent of the time, pretrained subjects who resolved three or more 12.0 cpd gratings had Snellen letter acuities of less than 20/40 (20/50, 20/70, or 20/100).

Summary

Only pupil-control biofeedback training produced a significant change; the average subject receiving pupil size biofeedback had a smaller pupil on day-5 than his average untrained counterpart. In spite of a universal improvement in Snellen letter acuity displayed by those receiving pupillary biofeedback training, there was no significant difference between trained and untrained subjects' acuity enhancements.

Neither accommodation flexibility nor blur interpretation training significantly influenced accommodative range or blur tolerance. Those receiving accommodative flexibility training displayed significant improvements in their 12.0 and 18.0 cpd grating resolution performances. After blur interpretation training, subjects displayed significantly larger changes in their Snellen letter recognition acuities and were able to resolve

between one and three more posttraining 6.0 cpd gratings than in pretraining.

When the three treatment groups are compared, there are no significant differences between pre- or posttraining performances on any of the vision performance tasks except contrast sensitivity. More 6.0 and 18.0 cpd grating and total contrast sensitivity performance improvement was made by subjects receiving either accommodative range training or blur interpretation training than by subjects receiving pupil biofeedback training.

High- and low-contrast Tumbling E resolution performances tie as the best predictors of Snellen letter recognition acuities. Inaccuracies are likely if VISTECH "equivalent acuity" contrast sensitivity performance is used to predict Snellen letter recognition performance or, conversely, if Snellen letter recognition performance is used to estimate "normal" contrast sensitivity.

CONCLUSIONS

Acuity of myopes can be enhanced through operant training. Consecutive-day practice and training produced significant acuity improvement after as few as three 1-hour sessions depending on the type of training. Even subjects who merely watched distant music videos between acuity assessments displayed superior acuity enhancement when compared with totally untreated subjects. This investigation substantiates improvement in acuity as a result of both specific treatments and general task repetition. Data analysis suggests that a one-time measurement of untrained subjects may not accurately assess their acuity.

As subjects were trained in only high-contrast Tumbling E resolution, posttraining performance improvements on the other five acuity tests support the contention that acuity is not only trainable but generalizes to other than treatment stimuli. The high correlations between these performance measures and their training-induced enhancements increase the viability of acuity training. The selection of stimuli in a training program might be dictated by procurement costs or availability with minimal compromise to nontreatment stimuli. For example, if stereoscope slide availability is limited, training with Tumbling E's seems to facilitate Ortho-Rater stereoscope checkerboard resolution.

Combinations of fading and feedback had differential effects on acuity enhancements but the performance improvement superiority of subjects trained with fading and verbal feedback was significant in many cases and nearly universally superior regardless of the acuity assessment technique. Subjects who received fading-and-feedback training displayed significantly

more improvements in Ortho-Rater checkerboard acuity and high-contrast Tumbling E acuity than those who received no treatment. Fading-and-feedback treatment facilitated better average Snellen letter acuity on day-5 than a no-treatment regimen. Only fading and feedback subjects displayed significant Snellen letter acuity enhancement over five days of participation.

Fading appears to be a critical treatment component if Tumbling E acuity enhancement was a priority. Only those subjects receiving treatments incorporating fading, repeatedly attempting to resolve E's of varying size, displayed significant improvements in high- and low-contrast Tumbling E acuities. Feedback was essential if Snellen letter recognition or Ortho-Rater checkerboard acuity enhancement was essential. Subjects were more than twice as likely to improve in Ortho-Rater acuity if they were provided verbal feedback or given the opportunity to discern their own feedback. There was significantly more Snellen letter acuity improvement made by those trained with fading and nonverbal but discernible feedback than by those treated with fading and no feedback.

Feedback is hypothesized to be an important component in motivation. Subjective experimenter observation confirmed by objective questionnaire responses supported the contention that those subjects trained with fading and no feedback were less motivated to participate and less encouraged to <u>try</u> to improve. Although their degree of motivation may have been less than their counterparts in other groups, one must not overlook the exceptionally high motivation levels of subjects in this investigation. Subjects were unpaid volunteers, participating during very limited free time, with a common goal of bettering their acuity and chances to enter undergraduate pilot training. Such a strong incentive may make the findings in this investigation less

generalizable to another population. The heightened subject motivation may, conversely, prove critical in discerning minute acuity changes that are susceptible to observer effort. Investigations of acuity enhancement that fail to keep motivation high may be inadvertently lessening possible treatment enhancement effects.

Different tests resulted in dissimilar assessments of acuity and different conclusions regarding the usefulness of acuity training. Regardless of the regimen, anywhere from 50 to 90 percent of the subjects in Experiment One displayed visual performance improvements in Snellen letter recognition, Ortho-Rater checkerboard acuity, high-contrast Tumbling E acuity, low-contrast Tumbling E acuity, or blurry letter recognition. With the exception of blurry Tumbling E recognition tolerance and pupil size, all of the acuity measures investigated in Experiment One reflected consistent treatment-induced enhancements.

The high pretraining, posttraining, and resultant performance change correlations between Snellen letter recognition, Ortho-Rater checkerboard resolution, and Tumbling E recognition might suggest that if one type of acuity was known, then others could be adequately estimated. To some degree this investigation supported such reciprocity. But when a person must display 20/70 Snellen letter acuity to enter a training program or when one must demonstrate 20/50 acuity to qualify to perform a task without glasses, any discrepancy or inaccuracy in prediction can become critical. The reversals between such Ortho-Rater and Snellen letter recognition criterion-based decisions discussed earlier made measurement and possibly training on each type of stimuli important considerations in screening and attempting to facilitate acuity. Possibly a battery of acuity tests would better serve to assess acuity. A multivariate acuity measurement

might identify subjects with large discrepancies between test performances, those subjects being most likely to benefit from training.

Contrast sensitivity, measured through VISTECH chart performance in this investigation, did not help resolve discrepancies between acuity measures. More than 20 percent of the the subjects in this investigation displayed "normal" contrast sensitivity when their Snellen letter recognition acuities were less than 20/20. Similarly, even some subjects' individual frequency performances, purported by VISTECH to reflect an "equivalent acuity value", grossly misrepresented their pretrained Snellen letter acuities.

Contrast sensitivity might be used very profitably, with training of the nature used in this investigation, in the area of subject selection. A person might be very likely to have a resultant acuity improvement after fading and feedback training if preliminary measurement revealed pretraining substandard Snellen or Ortho-Rater acuity contrast sensitivity in or above the "normal" range. In this investigation, all three of the subjects with "normal" contrast sensitivity but less than initial 20/20 Snellen letter acuity who were treated with fading and feedback recognized smaller letters on their fifth day of participation. Large inconsistencies among acuity values obtained using different techniques may likewise facilitate subject selection and aid in choosing the best training stimuli. If a person is capable of reading only 20/70 on a Snellen chart but can resolve 20/50 Ortho-Rater checkerboard patterns, training with Snellen letter stimuli will likely result in Snellen acuity enhancement.

The Snellen-letter measured acuity change for 30 subjects in Experiment One was predictable from the linear combination of logarithmically transformed pretraining Snellen acuity, change in blurry Tumbling E

recognition, and change in blurry letter recognition. When dummy variables were introduced into the equation to account for the type of training, the only treatment that was further predictive of acuity change was fading and no feedback. It appears that pupil size change and blur interpretation changes are important components in acuity enhancement. It is not known, however, how the treatments in this investigation influenced refractive error or to what degree general anxiety reduction facilitated acuity enhancement.

Retesting between four and seven weeks after training confirmed the notion that no regression in Ortho-Rater checkerboard acuity or high-contrast Tumbling E acuity would occur. Slight regression in Snellen letter acuity, low-contrast Tumbling E acuity, and contrast sensitivity was rare enough to support a contention that subjects learned processing techniques that endured enough to allow their application weeks after training. In fact, two subjects reported to the investigator that after their training, they passed pilot candidate qualification physicals. Each person's acuity had improved at least two line graduations on the Snellen chart when compared with their pretraining Snellen letter performances.

In Experiment Two, it was expected that after five days of participation there would be a greater change in the training-specific facets of acuity for treatment group members than for their untreated counterparts. This was true for only those receiving pupil size biofeedback training. The smaller pupil and any resultant increased depth of focus failed to facilitate significant acuity enhancement. Excluding contrast sensitivity, neither accommodative range training nor blur interpretation training improved posttraining acuity. Any of these three acuity treatments may be appropriate for a particular subject when pretraining measurements reflect an unusually large pupil,

poor accommodative range, or exceptionally inferior blur interpretation.

The accommodative range training in this investigation left unanswered the question of to what degree lens shape actually changed. The performance change might as well have been facilitated by blur interpretation. Nonobtrusive incorporation of a covert tracking optometer (Cornsweet & Crane, 1970) would have allowed more direct measurement of accommodative changes.

Further research with the assistance of a professional eye examiner is warranted. A logical extension of operant training evaluation might incorporate a double-blind experimental design where an optometrist or ophthalmologist assesses an observer's refractive error and acuity before and after another individual conducts operant training. If enhancement of Snellen letter recognition acuity is a priority, then the subject should be trained with high-contrast Snellen letters. However generalization in this investigation suggests that training with other stimuli (e.g., Tumbling E stimuli) will facilitate acuity improvement. In addition, if a subject displays large acuity discrepancies between his right and left eyes, some or all training might be accomplished with the stronger eye patched. Any of these approaches would increase our knowledge of what role operant training might play in facilitating acuity improvement. Further research in this area is warranted and has immediate application. Evaluation of the practicality of operant training in acuity enhancement is needed if objective assessments of visual performance are to be realized and possible augmentation techniques are to be evaluated for appropriateness and utility.

REFERENCES

Angle, J., & Wissmann, D. A. (1980). The epidemiology of myopia. American Journal of Epidemiology, 111, 220-228.

Baldwin, W. R. (1964). The relationship between axial length of the eye and certain other anthropomorphic measures of myopes. American Journal of Optometry and Archives of American Academy of Optometry, 41, 513-522.

Balliet, R., Clay, A., & Blood, K. (1982). The training of visual acuity in myopia. Journal of the American Optometry Association, 53, 719-724.

Bandura, A. (1969). Principles of Behavior Modification. New York: Holt, Rinehart and Winston.

Bates, W. H. (1920). The Bates Method for Better Eyesight Without Glasses. New York: Holt.

Bedrossian, R. H. (1964). Effect of Atropine on Myopia. Chicago: Professional Press.

Berens, C., Girard, L. J., Fonda, G., & Sells, S. B. (1957). Effects of tachistoscopic training on visual functions in myopic patients. American Journal of Ophthalmology, 44, 25-48.

Berman, P. E., Levinger, S., Massoth, N. A., Gallagher, D., Kalmar, K., & Pos, L. (1985). The effectiveness of biofeedback visual training as a viable method of treatment and reduction of myopia. Journal of Optometry and Visual Development, 16, 17-21.

Birnbaum, M. H. (1981). Clinical management of myopia. American Journal of Optometry and Physiological Optics, 58, 554-559.

Blackwell, H. R. (1952). Studies of psychophysical methods for measuring visual thresholds. Journal of the Optical Society of America, 42, 606-616.

Blount, R. L., Collins, F. L., Jr., & Gil, K. M. (1981, November). Environmental influences on the refractive state of the eye in myopic students. Paper presented at the meeting of the Association for Advancement of Behavior Therapy, Toronto, Canada.

Campbell, F. W. (1959). The accommodation response of the human eye. British Journal of Physiological Optics, 16, 188-203.

Campbell, F. W., & Green, D. G. (1965). Optical and retinal factors affecting visual resolution. Journal of Physiology, 181, 576-593.

Campbell, F. W., & Robson, J. G. (1968). Application of Fourier analysis to the visibility of gratings. Journal of Physiology, 197, 551-566.

Campbell, F. W., & Westheimer, G. (1959). Factors influencing accommodation responses of the human eye. Journal of the Optical Society of America, 49, 568-571.

Carr, H. (1907). Apparent control of the position of the visual field. Psychological Review, 14, 357-382.

Carr, H., & Allen, J. B. (1906). A study of certain relations of accommodation and convergence to the judgement of the third dimension. Psychological Review, 13, 258-275.

Coleman, D. J., & Trokel, S. (1969). Direct-recorded intraocular pressure variations in a human subject. Archives of Ophthalmology, 82, 637-640.

Collins, F. L., Jr., Epstein, L. H., & Hannay, H. J. (1981). A component analysis of an operant training program for improving visual acuity in myopic students. Behavior Therapy, 12, 692-701.

Collins, F. L., Epstein, L. H., & Gil, K. M. (1982). Behavioral factors in the etiology and treatment of myopia. In M. Herson, R. M. Eisler, & P. M. Miller (Eds.), Progress in Behavioral Modification (Vol. 13). New York: Academic Press.

Collins, F. L., Gil, K. M., & Ricci, J. A. (1982, October). Effectiveness of behavioral training for improving visual acuity in myopia: Improved clarity versus blur discrimination. A paper presented at the U.S.A. Interim Meeting of the International Society for Myopia Research, San Francisco, CA.

Copeland, V. L. (1967). Increased visual acuity of myopes while in hypnosis. Journal of the American Optometry Association, 38, 663-664.

Corbett, M. D. (1957). A Quick Guide to Better Vision. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Cornsweet, T. N., & Crane, H. D. (1970). Servo-controlled infrared optometer. Journal of the Optical Society of America, 60, 548-554.

Cornsweet, T. N., & Crane, H. D. (1973). Training the visual accommodative system. Vision Research, 13, 713-715.

Curtin, B. J., & Karlin D. B. (1971). Avial length measurements and fundus changes in the myopic eye. American Journal of Ophthalmology, 71, 42-53.

Dunphy, E. B. (1970). The biology of myopia. New England Journal of Medicine, 283, 796-800.

Dunphy, E. B., Stoll M. R., & King, S. H. (1968). Myopia among American male graduate students. American Journal of Ophthalmology, 65, 518-521.

Epstein L. H., Collins, F. L., Hannay, H. J. & Looney, R. L. (1978). Fading and feedback in the modification of visual acuity. Journal of Behavioral Medicine, 1, 273-297.

Fento[illegible], Collins, F. L., Burkett, P. A., & Amato, C. (1981, March). An evaluation of acuity changes following fading and feedback training. A paper presented at the meeting of the Southeastern Psychological Association, Atlanta, GA.

Friedman, E. (1981). Vision training program for myopia management. American Journal of Optometry and Physiological Optics, 58, 546-553.

Gallaway, M., Pearl, S. M., Winkelstein, A. M., & Scheiman, M. (1987). Biofeedback training of visual acuity and myopia: A pilot study. American Journal of Optometry & Physiological Optics, 64, 62-71.

Gawron, V. J. (1983). Ocular accommodation, personality, and autonomic balance. American Journal of Optometry and Physiological Optics, 60, 630-639.

Gervais, M. J., Harvey, L. O., Jr., & Roberts, J. O. (1984). Identification confusions among letters of the alphabet. Journal of Experimental Psychology: Human Perception and Performance, 10, 655-666.

Gibson, E. J. (1953). Improvement in perceptual judgments as a function of controlled practice or training. Psychological Bulletin, 50, 401-431.

Giddings, J. W., & Lanyon, R. I. (1971). Modification of refractive error through conditioning: an exploratory study. Behavior Therapy, 2, 538-542.

Giddings, J. W., & Lanyon, R. I. (1974). Effect of reinforcement of visual acuity in myopic adults. American Journal of Optometry and Physiological Optics, 51, 181-186.

Gil, K. M., & Collins, F. L., Jr. (1982, November). The use of a computerized video system as a training medium for modifying visual acuity in myopes. Paper presented at the meeting of the Association for Advancement of Behavior Therapy, Los Angeles, CA.

Gilmartin, B., & Hogan, R. E. (1985). The role of the sympathetic nervous system in ocular accommodation and ametropia. Ophthalmology and Physiological Optics, 5, 91-93.

Ginsburg, A. P., Easterly, J., & Evans, D. W. (1983). Contrast sensitivity predicts target detection field perfomrance of pilots. Proceedings of the Human Factors Society. (27th Annual Meeting): 269-273.

Goldschmidt, E. (1968). On the etiology of myopia. Acta Ophthalmologica Supplementum, 98, 1-172.

Goodson, R. A., & Rahe, A. J. (1981). Visual training effects on normal vision. American Journal of Optometry and Physiological Optics, 58, 787-791.

Goss, D. A. (1982). Attempts to reduce the rate of increase of myopia in young people - a critical literature review. American Journal of Optometry and Physiological Optics, 59, 828-841.

Haber, R. N., & Hershenson, M. (1980). The Psychology of Visual Perception (Second Edition). New York: Holt, Rinehart and Winston.

Harris, D. H. (1974). Accommodative-convergence control in myopia reduction. Journal of the American Optometry Association, 45, 292-296.

Harrison, B. T. (1929). Ophthalmic school clinics. Public Health, May, 1929.

Hildreth, H. R., Meinberg, W. H., Milder, B., Post, L. T., & Sanders, T. E. (1947). The effect of visual training on existing myopia. American Journal of Ophthalmology, 30, 1563-1576.

Hirsch, M. J. (1952). The changes in refraction between the ages of 5 and 14 - theoretical and practical considerations. American Journal of Optometry and Archives of American Academy of Optometry, 29, 445-449.

Hirsch, M. J. (1959). The relationship between refractive state of the eye and intelligence test scores. American Journal of Optometry and Archives of American Academy of Optometry, 36, 12-21.

Hirsch, M. J. (1968). Summary of current research on refractive anomalies. Optometric Weekly, 59, 31-34.

Hirsch, M. J., & Ditmar, D. L. (1969). Refraction of young myopes and their parents: a reanalysis. American Journal of Optometry and Archives of American Academy of Optometry, 46, 30-32.

Honmura, S. (1968). Studies on the relationship between ocular tension and myopia (English summary). Acta Societatis Ophthalmologicae Japonicae, 72, 671-698.

Huxley, A. L. (1942). The Art of Seeing. New York: Harper & Brothers.

Kantor, D. (1932). Racial aspects of myopia in compositors. British Journal of Ophthalmology, 16, 49-50.

Kelley, C. R. (1962). Psychological factors in myopia. Journal of the American Optometric Association, 33, 833-837.

Kelly, T. S-B., Chatfield, C., & Tustin, G. (1975). Clinical assessment of the arrest of myopia. British Journal of Ophthalmology, 59, 529-538.

Kerns, R. L. (1981). Contact lens control of myopia. American Journal of Optometry and Physiological Optics, 58, 541-545.

Kruger, P. B., & Pola J. (1986). Stimuli for accommodation: Blur, chromatic aberration and size. Vision Research, 26, 957-971.

Ku, D. N., & Greene, P. R. (1981). Scleral creep in vitro resulting from cyclic pressure pulses: applications to myopia. American Journal of Optometry and Physiological Optics, 58, 528-535.

Lanyon, R. I., & Giddings, J. W. (1974). Psychological approaches to myopia: A review. American Journal of Optometry and Physiological Optics, 51, 271-281.

Leibowitz, H. W. (1952). The effect of pupil size on visual acuity for photometrically equated test fields at various levels of luminance. Journal of the Optical Society of America, 42, 416-422.

Leibowitz, H. W., & Owens, D. A. (1978). New evidence for the intermediate position of relaxed accommodation. Documenta Ophthalmologica, 46, 133-147.

Lupica, V. P. (1976). Hypnosis therapy for ciliary spasms. Journal of the American Optometry Association, 47, 102-108.

Malmstrom, F. V., & Randle, R. J. (1976). Effects of visual imagery on the accommodation response. Perception & Psychophysics, 19, 450-453.

Marg, E. (1952). Flashes of clear vision and negative accommodation with reference to the Bates method of visual training. American Journal of Optometry and Archives of American Academy of Optometry, 29, 167-184.

Michaels, D. D. (1975). Visual Optics and Refraction. St. Louis: Mosby.

Miller, N. E. (1969). The learning of visceral and glandular responses. Science, 163, 434-445.

Morgan, M. W. (1944). The nervous control of accommodation. American Journal of Optometry and Archives of American Academy of Optometry, 21, 87-93.

Morgan, M. W. (1957). The resting state of accommodation. American Journal of Optometry and Archives of American Academy of Optometry, 34, 347-353.

Mull, H. K. (1948). Myopia and introversion. American Journal of Psychology, 61, 575-576.

Nolan, J. A. (1974). An approach to myopia control. Optometric Weekly, 65,149-154.

Oakley, K. H., & Young, F. A. (1975). Bifocal control of myopia. American Journal of Optometry and Physiological Optics, 52, 758-764.

Ogle, K. N. (1961). Foveal contrast thresholds with blurring of the retinal image and increasing size of test stimulus. Journal of the Optical Society of America, 51, 862-869.

Ogle, K. N. (1962). Blurring of retinal image and foveal contrast thresholds of separated point light sources. Journal of the Optical Society of America, 52, 1035-1039.

O'Neal, M. R., & Miller, R. E. (in press). Further Investigation of Contrast Sensitivity and Visual Acuity in Pilot Detection of Aircraft. Wright-Patterson AFB, OH: Armstrong Aerospace Medical Research Laboratory.

Owens, D. (1980). A comparison of accommodation responsiveness and contrast sensitivity and sinusoidal gratings. Vision Research, 20, 159-167.

Owens, D. A., & Leibowitz, H. W. (1976). Night myopia; cause and a possible basis for amelioration. American Journal of Optometry and Physiological Optics, 53, 709-717.

Owsley, C., Sekuler, R., & Siemsen, D. (1983). Contrast sensitivity throughout adulthood. Vision Research, 23, 689-699.

Palmer, R. D. (1966). Visual acuity and excitement. Psychosomatic Medicine, 28, 364-374.

Peppard, H. M. (1940). Sight Without Glasses. New York: Blue Ribbon Books, Inc.

Provine, R. R., & Enoch, J. M. (1975). On voluntary ocular accommodation. Perception and Psychophysics, 17, 209-212.

Randle, R. J. (1970). Volitional control of visual accommodation. Conference Proceedings No. 82 on Adaptation and Acclimitization in Aerospace Medicine, AGARD, NATO (pp. 20.0-20.11), Garmisch-Partenkirchen, Germany, 14-18 September, 1970.

Randle, R. J. (1975). The non-visual in visual accommodation. International Conference on Cybernetics and Society, 323-326.

Randle, R. J. (1985). Behavioral myopia remission using biofeedback (Phase I Final Report). Las Cruces, NM: ILLIANA Aviation Sciences Limited.

Renshaw, S. (1945). Tachistoscope in visual diagnosis and training. Optometric Weekly, 36, 1189.

Ricci, J. A., & Collins, F. L. (1981). The role of psychology in the health care of ophthalmological disorders. Clinical Psychology Review, 1, 431-451.

Ripps, H., Chin, N. B., Siegel, I. M., & Breinin, G. M. (1962). The effect of pupil size on accommodation, convergence and the AC/A ratio. Investigative Ophthalmology, 1, 127-135.

Roberts, W. L., & Banford, R. D. (1967). Evaluation of bifocal correction technique in juvenile myopia. Optometric Weekly, 58(38), 25-31; 58(39), 21-27; 58(40), 23-28; 58(41), 27-34; 58(43), 19-29.

Roscoe, S. N., & Couchman, D. H. (1987). Improving visual performance through volitional focus control. Human Factors, 29, 311-325.

Sato, T. (1964). Acquired Myopia. Chicago: Professional Press.

Sells, S. B., & Fixott, R. S. (1957). Evaluation of research on effects of visual training on visual functions. American Journal of Ophthalmology, 44, 230-236.

Shlaer, S. (1937). The relation between visual acuity and illumination. Journal of General Physiology, 21, 165-188.

Shultz, L. B. (1960). Personality and physical variables as related to refractive errors. American Journal of Optometry and Archives of American Academy of Optometry, 37, 551-571.

Sission, E. D. (1938). Voluntary control of accommodation. Journal of General Psychology, 18, 195-198.

Slataper, F. J. (1950). Age norms of refraction and vision. Archives of Ophthalmology, 43, 466-481.

Sloan, L. L. (1951). Measurement of visual acuity. Archives of Ophthalmology, 45, 704-725.

Sloane, A. E., Dunphy, E. B., & Iannsons, W. V. (1948). The effects of single group training method upon myopia and visual acuity. Research Quarterly, 19, 111-117.

Snyder, C., & Noble, M. (1968). Operant conditioning of vasoconstriction. Journal of Experimental Psychology, 77, 263-268.

Sorsby, A. (1951). Genetics in Ophthalmology. St. Louis: C. V. Mosby Company.

Sperduto, R. D., Seigel, D., Roberts, J., & Rowland, M. (1983). Prevalence of myopia in the United States. Archives of Ophthalmology, 101, 405-407.

Stark, L., & Takahashi, Y. (1965). Absence of an odd-error signal mechanism in human accommodation. I.E.E.E. Transactions on Bio-Medical Engineering, 12, 138-146.

Stephens, K. G. (1985). Effect of the sympathetic nervous system on accommodation. American Journal of Optometry and Physiological Optics, 62, 402-406.

Stone, J. (1973). Contact lens wear in the young myope. British Journal of Physiological Optics, 28, 90-134.

Toates, F. M. (1970). Letter to the editors: A model of accommodation. Vision Research, 10, 1069-1076.

Toates, F. M. (1972). Accommodation function of the human eye. Physiological Reviews, 52, 828-863.

Trachtman, J. N. (1978). Biofeedback of accommodation to reduce functional myopia: A case report. American Journal of Optometry and Physiological Optics, 55, 400-406.

Trachtman, J. N. (1987). Biofeedback of accommodation to reduce myopia: A review. American Journal of Optometry and Physiological Optics, 64, 639-643.

Van Horn, P. L. (1984). Gains in visual acuity of myopes noted with biofeedback training. Optometry Times, 2.

Westheimer, G. (1957). Accommodation measurements in empty visual fields. Journal of the Optical Society of America, 47, 714-718.

Westheimer, G. (1965) Spatial interaction in the human retina during scotopic vision. Journal of Physiology, 181, 881-894.

Woods, A. C. (1946). Report from the Wilmer Institute on the result obtained in the treatment of myopia by visual training. American Journal of Ophthalmology, 29, 28-57.

Young, F. A. (1958). An estimate of the hereditary component of myopia. American Journal of Optometry and Archives of American Academy of Optometry , 35, 337-345.

Young, F. (1961). The development and retention of myopia by monkeys. American Journal of Optometry and Archives of American Academy of Optometry, 38, 545-555.

Young, F. A. (1963). Reading, measures of intelligence and refractive errors. American Journal of Optometry and Archives of American Academy of Optometry, 40, 257-264.

Young, F. A. (1965a). The etiology of myopia. Optometric Weekly. 56, 17-24.

Young, F. (1965b). The effect of atropine on the development of myopia in monkeys. American Journal of Optometry and Archives of American Academy of Optometry, 42, 439-449.

Young, F. A. (1966). Heredity and myopia in monkeys. Optometric Weekly, 57, 44-49.

Young, F. A. (1967). Myopia and personality. American Journal of Optometry and Archives of American Academy of Optometry, 44, 192-201.

Young, F. A. (1977). The nature and control of myopia. Journal of the American Optometric Association, 48, 451-457.

Young, F. A. (1981). Primate myopia. American Journal of Optometry and Physiological Optics, 58, 560-566.

Young, F. A., Baldwin, W. A., Leary, G. A., West, D. C., Box, R. A., Harris, E., & Johnson, C. (1969). The transmission of refractive errors within Eskimo families. American Journal of Optometry and Archives of American Academy of Optometry, 46, 676-685.

Young, F. A., Leary, G. A., Baldwin, W. R., West, D. C., Goo, F. J., Box, R. A., & Johnson, C. (1970). Refractive errors, reading performance, and school achievement among Eskimo children. American Journal of Optometry and Archives of American Academy of Optometry, 47, 384-390.

APPENDIX A:

Day-1 versus Day-5 Acuity Measurements

Table A-1

Experiment One Pretraining and 5th-Day Posttraining Snellen Acuities by Training Type

Pretraining Acuity	Training Type: Fading and Feedback	Fading (No Verbal Feedback)	Fading (No Feedback)	Feedback (No Fading)	No Treatment	Control (Day 1 and Day 5)
	Posttraining Acuity					
Initial 20/25 Snellen Letter Recognition Acuity	20/20	20/20	20/25	20/25	20/25	20/20
Initial 20/30 Snellen Letter Recognition Acuity	20/25	20/20	20/30	20/30	20/30	20/40
Initial 20/40 Snellen Letter Recognition Acuity	20/25	20/40	20/40	20/15	20/20	20/40
Initial 20/50 Snellen Letter Recognition Acuity	20/40	20/40	20/50	20/30	20/40	20/50
Initial 20/70 Snellen Letter Recognition Acuity	20/40	20/50	20/70	20/70	20/50	20/70
Initial 20/100 Snellen Letter Recognition Acuity	20/25	20/25	20/100	20/70	20/70	20/100

Table A-2

Experiment Two Pretraining and 5th-Day Posttraining Snellen Acuities by Training Type

Pretraining Acuity	Training Type					
	Pupillary Control		Accommodative Flexibility		Blur Interpretation	
	Training	Control	Training	Control	Training	Control
	Posttraining Acuity					
Initial 20/25 Snellen Letter Recognition Acuity	20/15	20/30	20/15	20/15	20/20	20/30
Initial 20/30 Snellen Letter Recognition Acuity	—		20/20	20/25	—	
Initial 20/40 Snellen Letter Recognition Acuity	20/25	20/20	—		20/25	20/50
Initial 20/50 Snellen Letter Recognition Acuity	20/30	20/50	20/20	20/40	—	
Initial 20/70 Snellen Letter Recognition Acuity	20/50	20/40	20/40	20/50	20/50	20/70
Initial 20/100 Snellen Letter Recognition Acuity	20/70	20/70	20/40	20/40	—	

APPENDIX B:

Visual Performance Measurement Correlations

Table B-1

Correlation Matrix for Pretraining Visual Performance Measurements

Visual Performance Assessment Technique	Ortho-Rater Acuity	High-Contrast Tumbling E Acuity	Low-Contrast Tumbling E Acuity	Total Contrast Sensitivity	1.5 cpd Contrast Sensitivity	3.0 cpd Contrast Sensitivity	6.0 cpd Contrast Sensitivity	12.0 cpd Contrast Sensitivity	18.0 cpd Contrast Sensitivity
Snellen Letter Acuity	.654	-.729	-.721	-.577	-.563	-.623	-.552	-.337***	-.411**
Ortho-Rater Acuity		-.777	-.772	-.771	-.720	-.747	-.628	-.582	-.645
High-Contrast Tumbling E Acuity			.993	.906	.749	.856	.840	.645	.799
Low-Contrast Tumbling E Acuity				.901	.757	.840	.837	.644	.793
Total Contrast Sensitivity					.820	.860	.916	.797	.907
1.5 cpd Contrast Sensitivity						.798	.699	.434*	.613
3.0 cpd Contrast Sensitivity							.705	.479*	.704
6.0 cpd Contrast Sensitivity								.756	.789
12.0 cpd Contrast Sensitivity									.722

N=30 All $p \leq 0.001$ except as noted

*$p \leq 0.020$

**$p \leq 0.025$

***$p \leq 0.065$

Table B-2

Correlation Matrix for Pre- and 5th-Day Posttraining Blur Tolerance Performance Measurements

Visual Performance Assessment Technique	Day-1 Tumbling E Blur Tolerance	Day-1 Letter Blur Tolerance	Day-5 Tumbling E Blur Tolerance	Day-5 Letter Blur Tolerance	Tumbling E Blur Tolerance Change	Letter Blur Tolerance Change
Pretraining Snellen Acuity	.014	-.533**	.106	.303	.094	.573*
Snellen Letter Acuity Change	.266	-.112	.312	.426***	.020	.578*
Pretraining Ortho-Rater Acuity	-.123	-.075	-.093	.122	.042	.214
Day-1 Tumbling E Blur Tolerance		.499**	.575*	.253	-.538**	-.224
Day-1 Letter Blur Tolerance			.325	-.543**	-.230	-.440***
Day-5 Tumbling E Blur Tolerance				.581*	.380****	.304
Day-5 Letter Blur Tolerance					.313	.513**
Tumbling E Blur Tolerance Change						.568**

N=30 *$p \leq 0.001$

**$p \leq 0.005$

***$p \leq 0.020$

****$p \leq 0.050$

Table B-3

Correlation Matrix for 5th -Day Posttraining Visual Performance Measurements

Visual Performance Assessment Technique	Ortho-Rater Acuity	High-Contrast Tumbling E Acuity	Low-Contrast Tumbling E Acuity	Total Contrast Sensitivity	1.5 cpd Contrast Sensitivity	3.0 cpd Contrast Sensitivity	6.0 cpd Contrast Sensitivity	12.0 cpd Contrast Sensitivity	18.0 cpd Contrast Sensitivity
Snellen Letter Acuity	.759	-.886	-.872	-.710	-.654	-.762	-.566*	-.567*	-.570*
Ortho-Rater Acuity		-.819	-.821	-.773	-.732	-.709	-.704	-.666	-.581
High-Contrast Tumbling E Acuity			.989	.850	.811	.814	.717	.710	.677
Low-Contrast Tumbling E Acuity				.867	.813	.827	.732	.713	.709
Total Contrast Sensitivity					.842	.835	.876	.865	.901
1.5 cpd Contrast Sensitivity						.822	.665	.567*	.688
3.0 cpd Contrast Sensitivity							.675	.575*	.627
6.0 cpd Contrast Sensitivity								.725	.699
12.0 cpd Contrast Sensitivity									.814

N=30 All $p \leq 0.001$ except as noted

*$p \leq 0.002$

Table B-4

Correlation Matrix for Posttraining Changes in Visual Performance Measurements

Visual Performance Assessment Technique	Ortho-Rater Acuity	High-Contrast Tumbling E Acuity	Low-Contrast Tumbling E Acuity	Total Contrast Sensitivity	1.5 cpd Contrast Sensitivity	3.0 cpd Contrast Sensitivity	6.0 cpd Contrast Sensitivity	12.0 cpd Contrast Sensitivity	18.0 cpd Contrast Sensitivity
Snellen Letter Acuity Change	.539**	.408***	.377****	.172	.043	.018	.123	.166	.080
Ortho-Rater Acuity Change		.466***	.496**	.497**	.016	.080	.248	.625*	.315
High-Contrast Tumbling E Change			.933*	.275	.090	.074	.277	.303	.241
Low-Contrast Tumbling E Change				.381****	.100	-.130	.368****	.306	.345
Total Contrast Sensitivity Change					.415***	.290	.555**	.697*	810*
1.5 cpd Contrast Sensitivity Change						.253	.028	-.135	.321
3.0 cpd Contrast Sensitivity Change							-.106	-.016	-.030
6.0 cpd Contrast Sensitivity Change								.222	.226
12.0 cpd Contrast Sensitivity Change									.670*

N=30

*$p \leq 0.001$

**$p \leq 0.005$

***$p \leq 0.025$

****$p \leq 0.050$

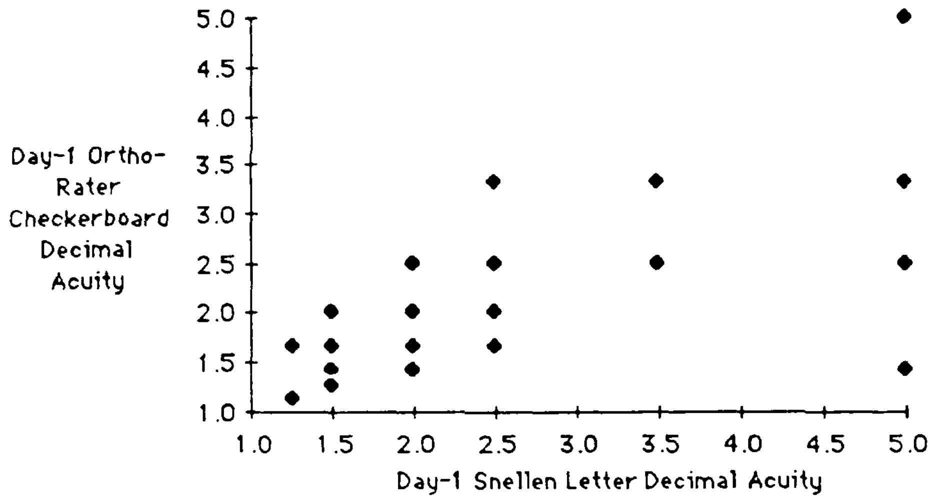

Figure B-1. Day-1 Snellen letter versus Ortho-Rater checkerboard acuity.

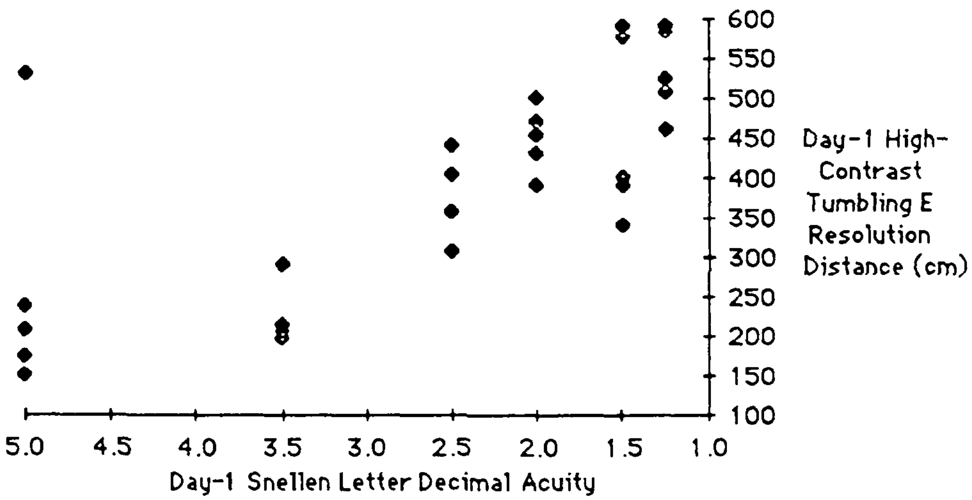

Figure B-2. Day-1 Snellen letter acuity versus high-contrast Tumbling E resolution distance.

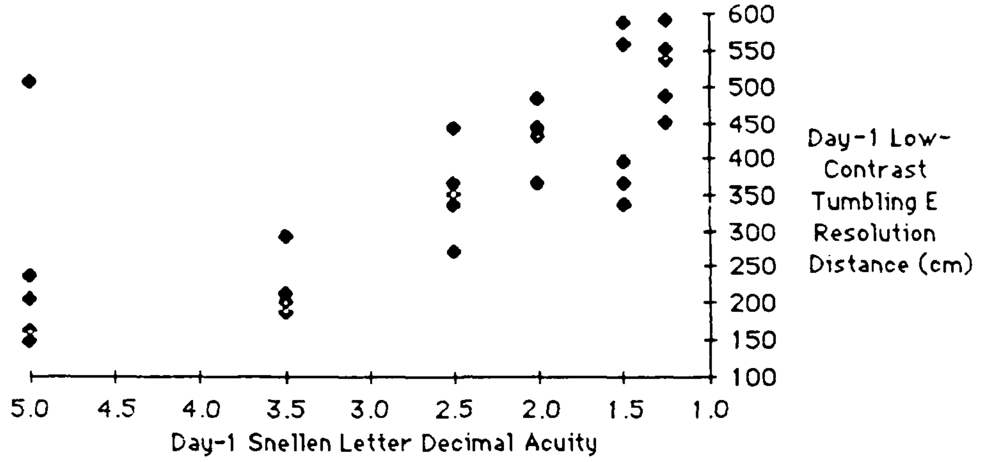

Figure B-3. Day-1 Snellen letter acuity versus low-contrast Tumbling E resolution distance.

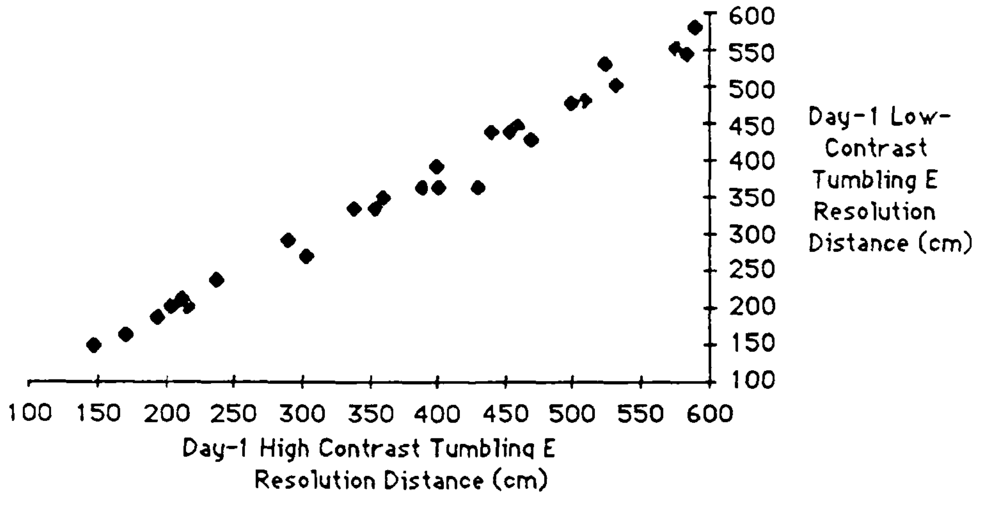

Figure B-4. Day-1 high- versus low-contrast Tumbling E resolution distance.

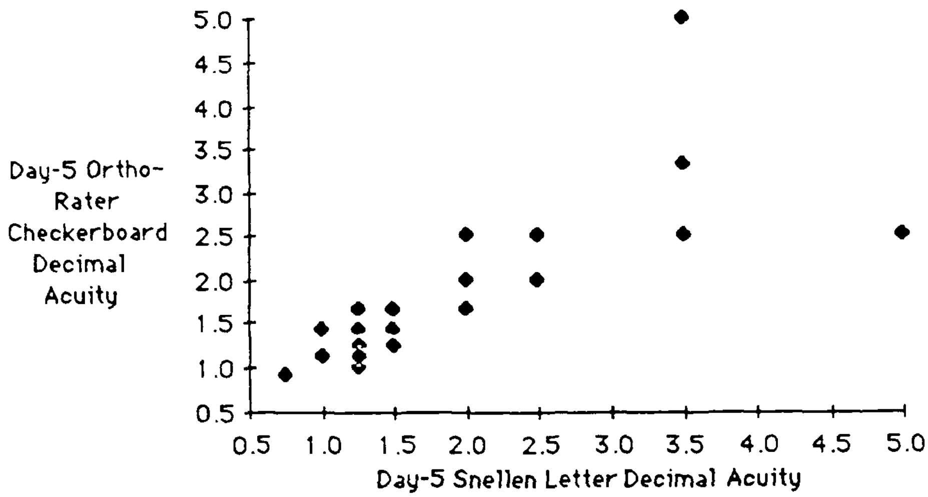

Figure B-5. Day-5 Snellen letter versus Ortho-Rater checkerboard acuity.

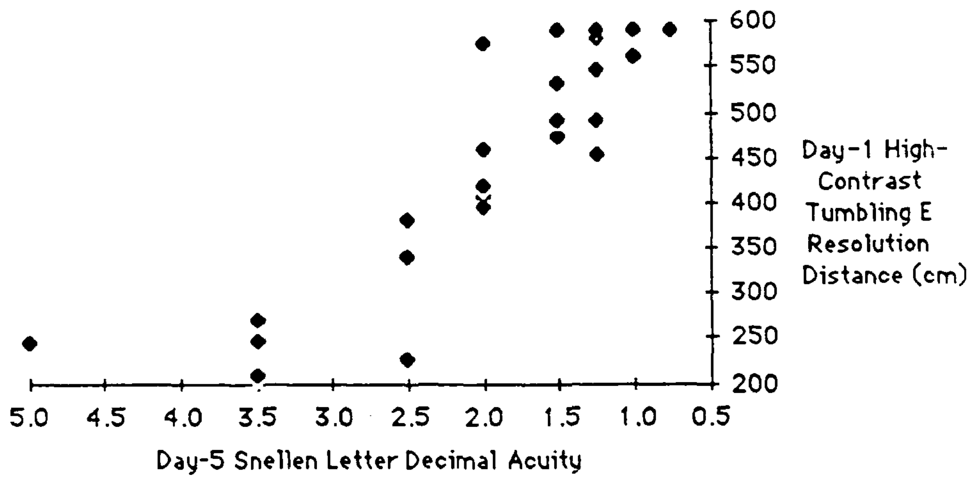

Figure B-6. Day-5 Snellen letter acuity versus high-contrast Tumbling E resolution distance.

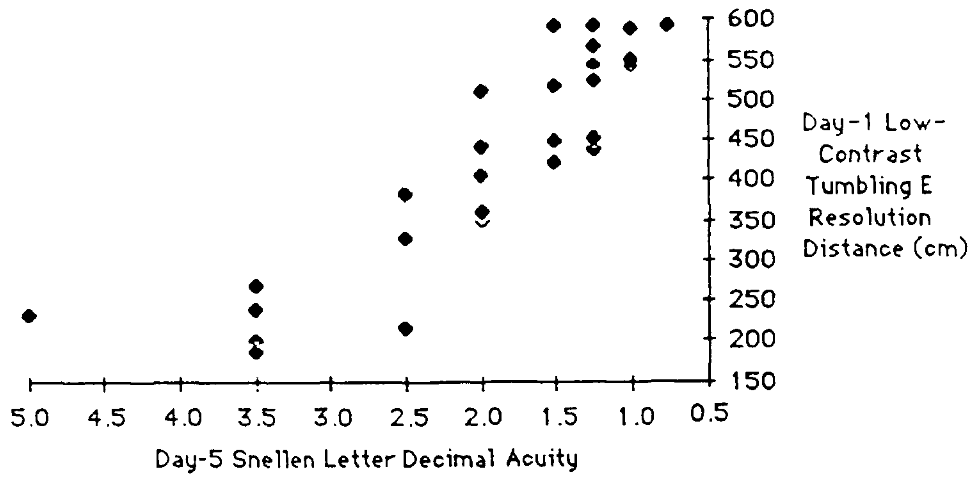

Figure B-7. Day-5 Snellen letter acuity versus low-contrast Tumbling E resolution distance.

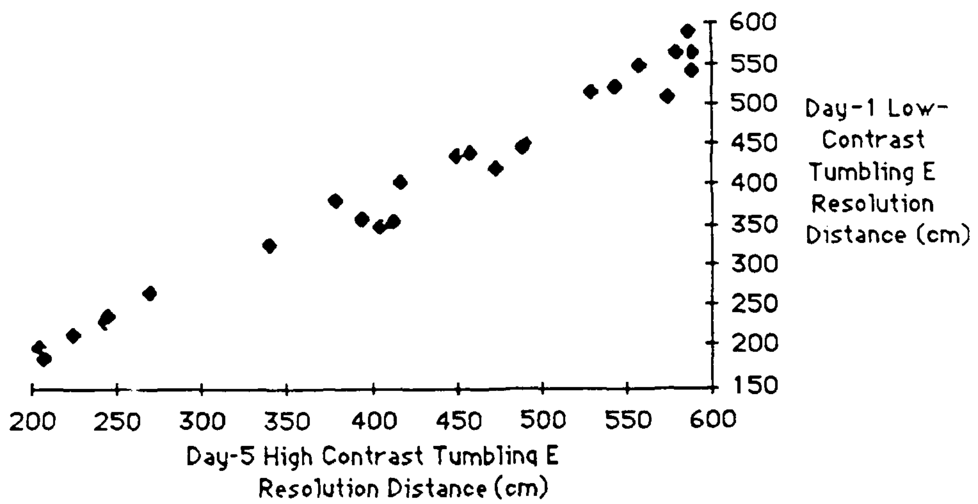

Figure B-8. Day-5 high- versus low-contrast Tumbling E resolution distance.

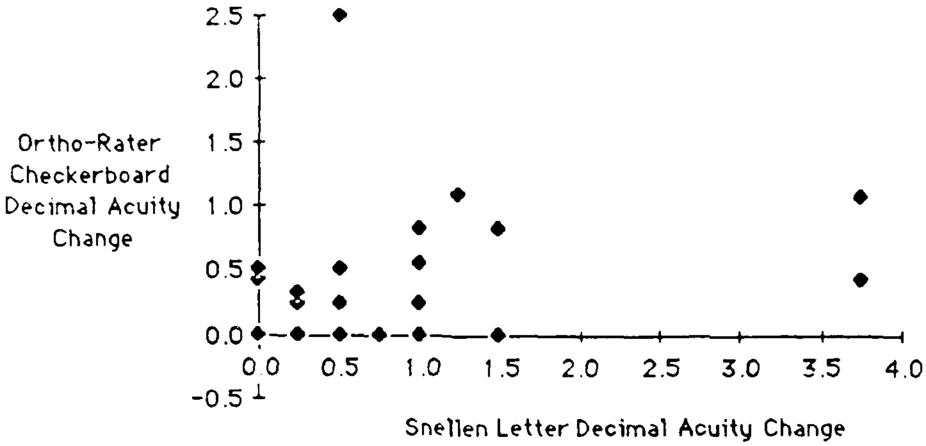

Figure B-9. Snellen letter versus Ortho-Rater checkerboard acuity change.

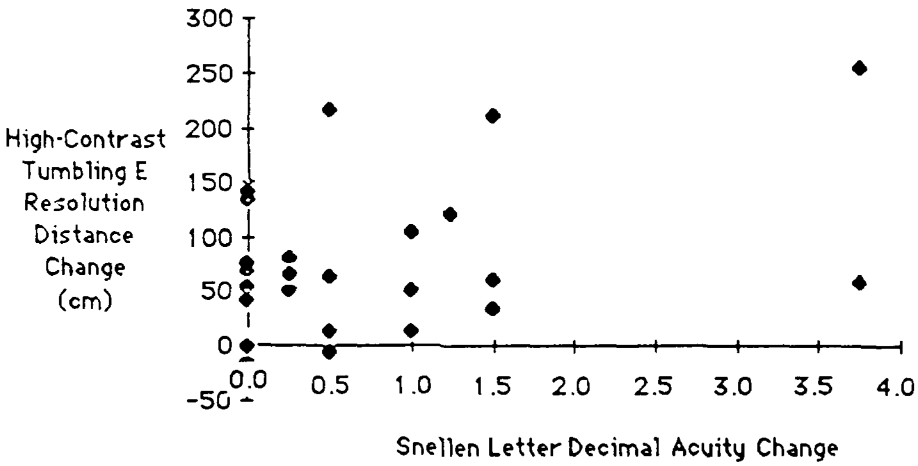

Figure B-10. Snellen letter acuity change versus high-contrast Tumbling E resolution distance change.

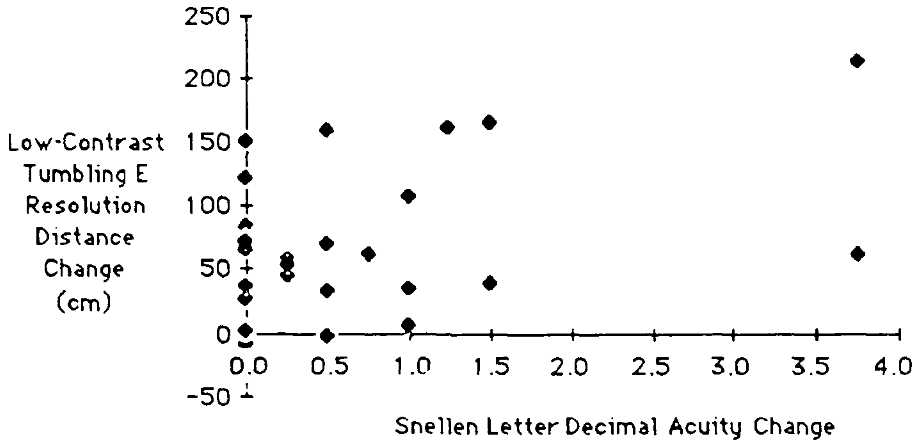

Figure B-11. Snellen letter acuity change versus low-contrast Tumbling E resolution distance change.

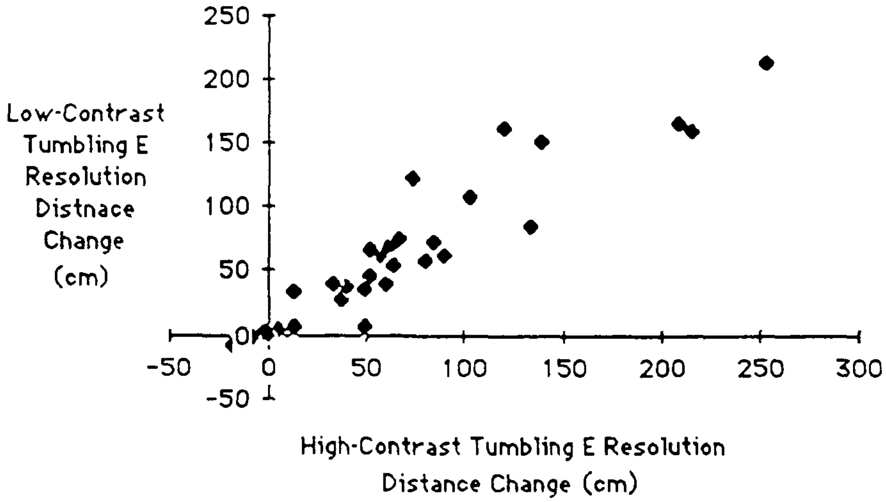

Figure B-12. High- versus low-contrast Tumbling E resolution distance change.

APPENDIX C:

VISTECH Grating Resolution Performance Measurements

by Pretrained Snellen Letter Acuity

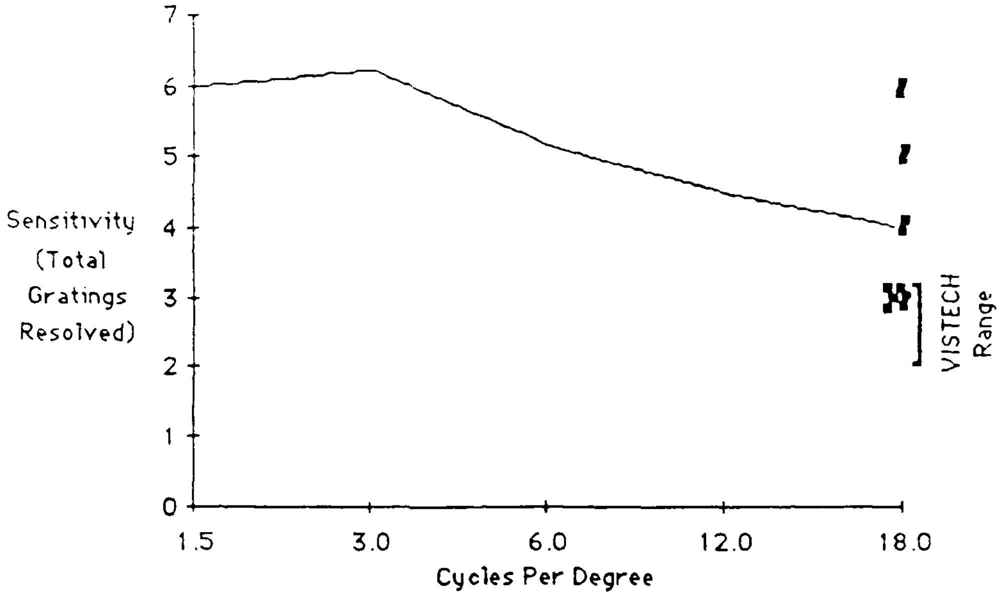

Figure C-1. Average pretrained 20/25 Sne...n letter acuity participant contrast sensitivity performance versus VISTECH "equivalent acuity values" (dots represent individual performance at the frequency VISTECH claims indicative of 20/25 acuity).

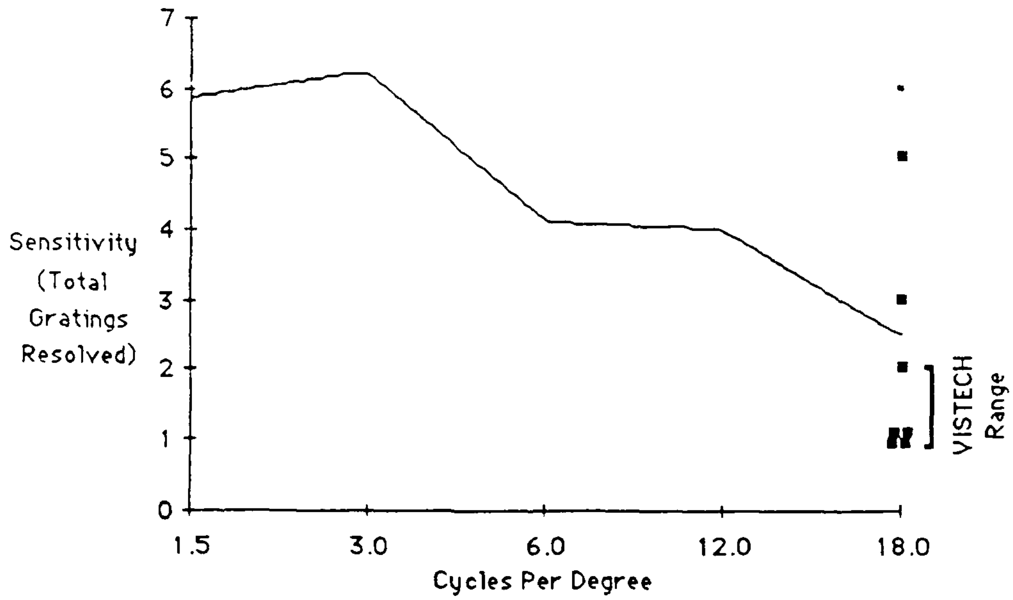

Figure C-2. Average pretrained 20/30 Snellen letter acuity participant contrast sensitivity performance versus VISTECH "equivalent acuity values" (dots represent individual performance at the frequency VISTECH claims indicative of 20/30 acuity).

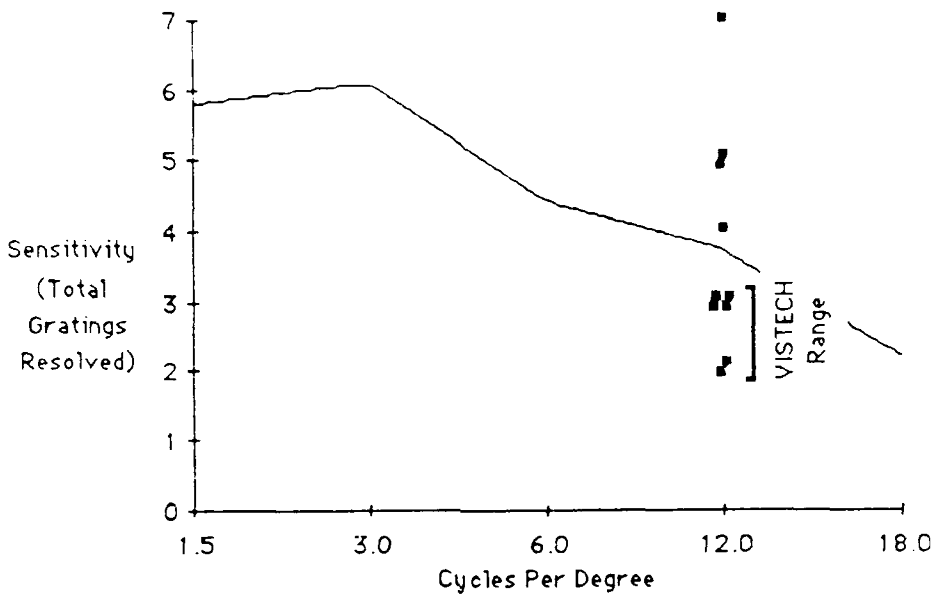

Figure C-3. Average pretrained 20/40 Snellen letter acuity participant contrast sensitivity performance versus VISTECH "equivalent acuity values" (dots represent individual performance at the frequency VISTECH claims indicative of 20/40 acuity).

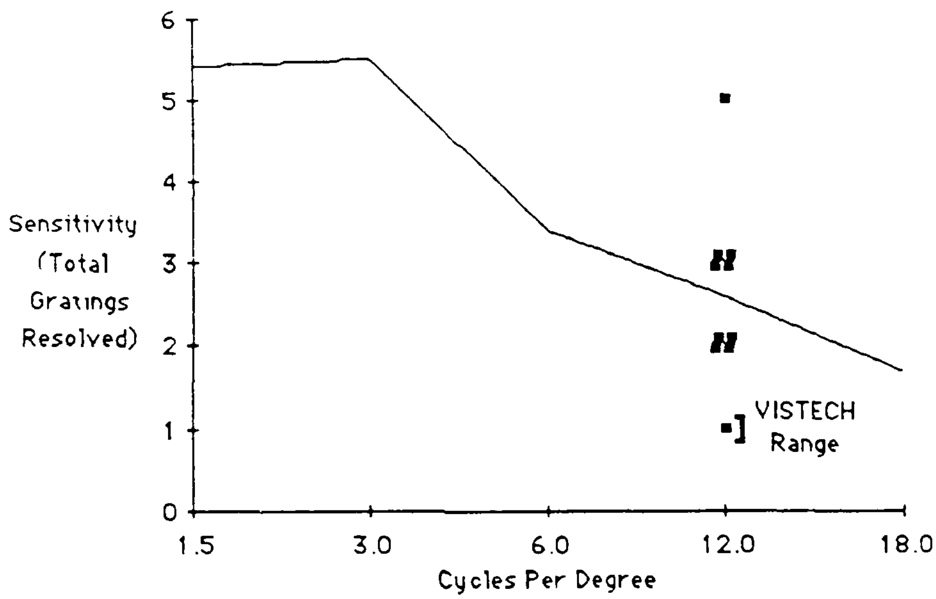

Figure C-4. Average pretrained 20/50 Snellen letter acuity participant contrast sensitivity performance versus VISTECH "equivalent acuity values" (dots represent individual performance at the frequency VISTECH claims indicative of 20/50 acuity).

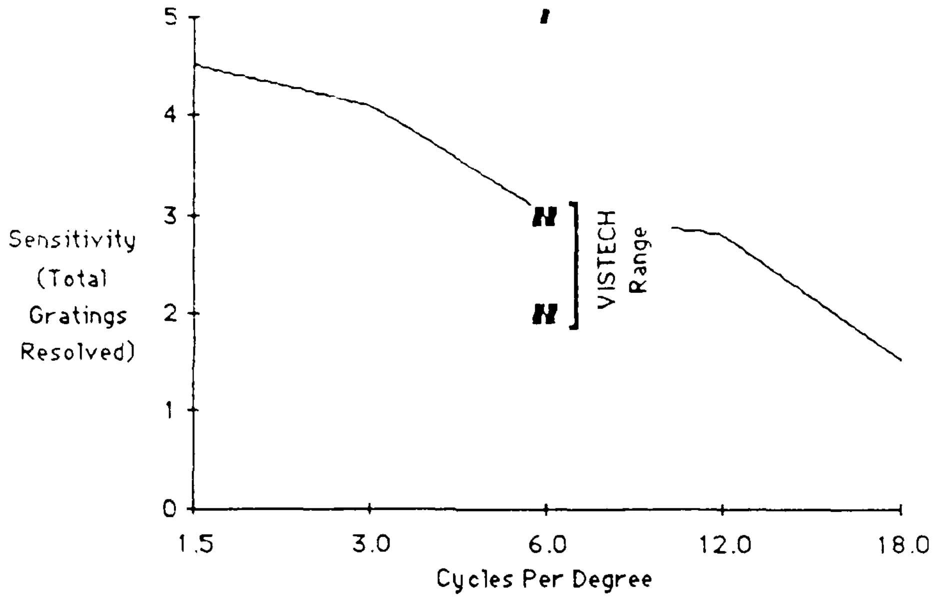

Figure C-5. Average pretrained 20/70 Snellen letter acuity participant contrast sensitivity performance versus VISTECH "equivalent acuity values" (dots represent individual performance at the frequency VISTECH claims indicative of 20/70 acuity).

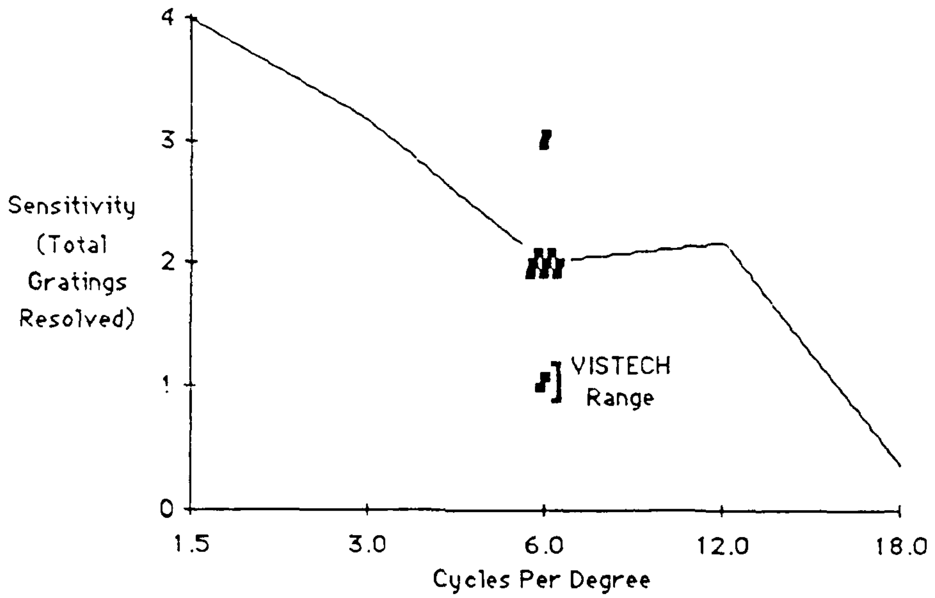

Figure C-6. Average pretrained 20/100 Snellen letter acuity participant contrast sensitivity performance versus VISTECH "equivalent acuity values" (dots represent individual performance at the frequency VISTECH claims indicative of 20/100 acuity).